ECONOMIC GEOLOGY

e – Learning Material: Unit-5

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CHROMIUM

Chromite is the only economic source of Chromium. It has a wide range of uses in metallurgical, chemical, refractory industries.

The properties of chromium that makes it most versatile and indispensable are its resistance to corrosion, oxidation, wear and galling and enhancement of hardenability.

In metallurgical industry, chromite is used for manufacturing low-carbon and high carbon ferro-chrome and charge chrome which in turn are used as additives in making stainless steels and special alloy steel.

Hard lumpy chromite is used for producing high carbon ferrochrome while friable ore and fines briquettes are used for low carbon ferrochrome. Both briquette fines and lumpy ores are used in production of charge chrome.

In chemical industry, chromite is used for production of sodium bichromate which is the source material for making various chromium-based chemicals.

These chrome-chemicals are used in chromium plating, leather tanning, furniture and fixtures, vehicles, safety matches, as dyes in clothings, drilling muds and as catalysts and pigments.

The most objectionable impurities are silica and lime.

In refractory industry, chromite is used as a refractory material because of its high melting point (1,700^o to 1,900^o C). Generally, refractories are made using magnesite and chromite together and depending on the chromite to dead-burnt magnesite (DBM) ratio, bricks are called chrome-mag bricks (50 to 55% chromite) and mag-chrome bricks (45 to 50% chromite).

Dense chrome bricks containing 100% chromite are also manufactured. Chromite refractories used for lining of open hearth steel furnaces serve as neutral refractories.

The refractory industry prefers hard lumpy ore containing low silica and low lime.

Chromite is also used in ceramic industry and electrode making industry

Chromite (FeCr2O4)

Chromium	46.46 %
Iron	24.95 %
Oxygen	28.59 %
	100.00 %

Cleavage: None

Color: Black, Brownish black.

Density: 4.5 - 5.09, Average = 4.79

Diaphaneity: Opaque

Fracture: Uneven - Flat surfaces (not cleavage) fractured in an uneven pattern.

Habit: Granular - Generally occurs as anhedral to subhedral crystals in matrix. Massive – Granular, Nuggets - Irregular lumps produced by stream transport

Hardness: 5.5 - Knife Blade

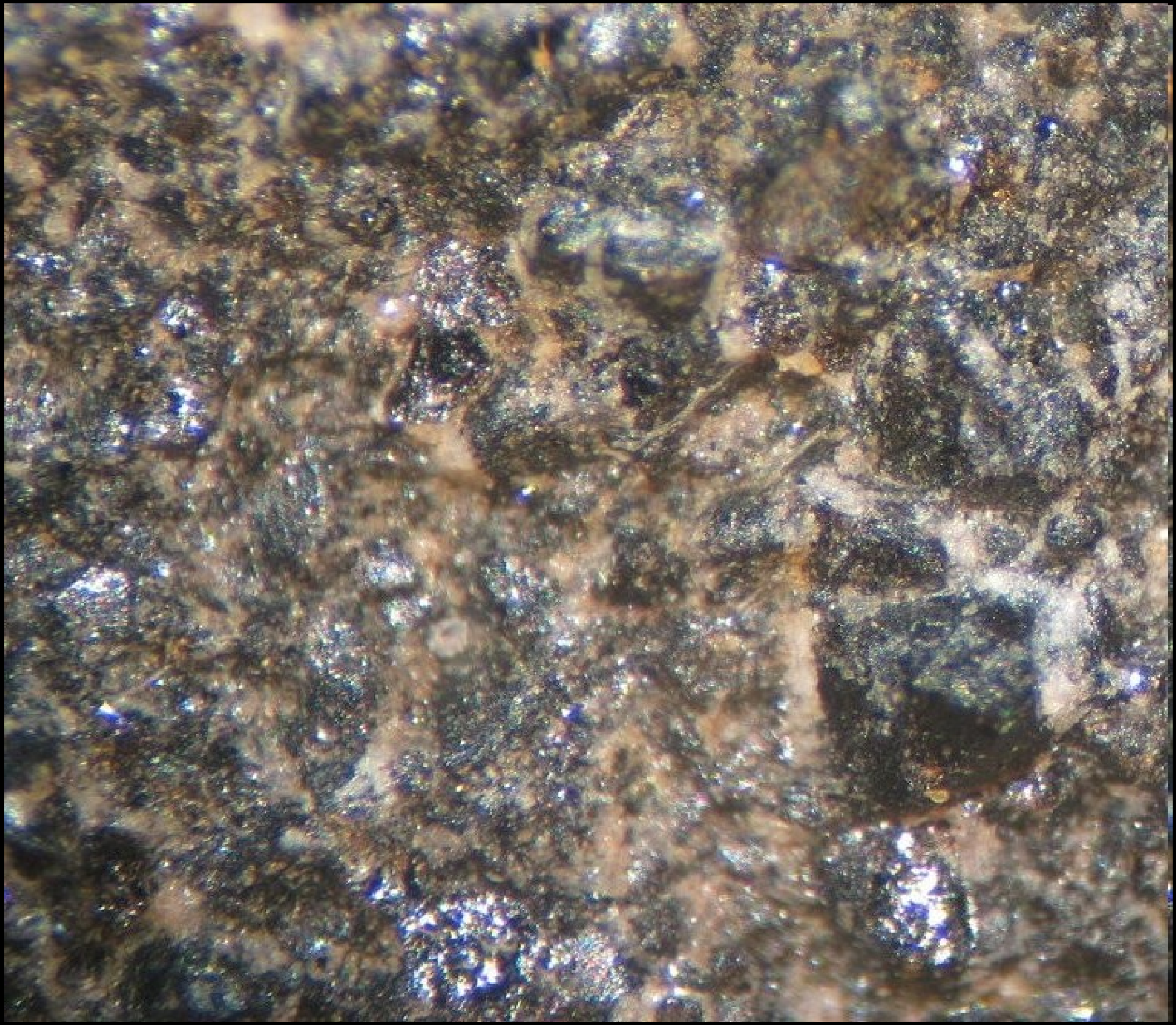
Luminescence: Non-fluorescent.

Luster: Metallic

Magnetism: Naturally weak

Streak: brown

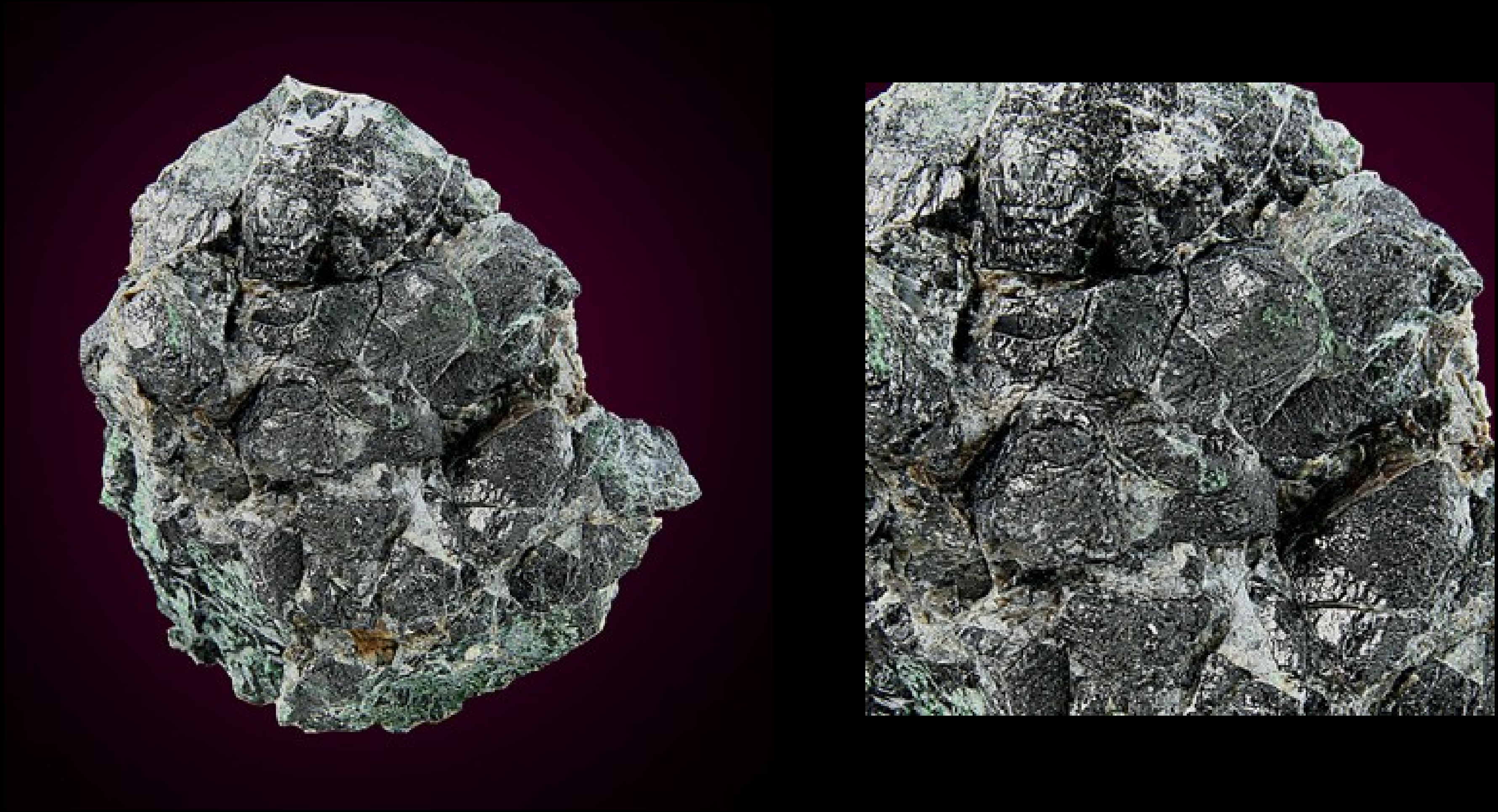
Environment: Cummulate mineral found in ultramafic portions of layered mafic intrusions. Common in meteorites. an accessory mineral in alpine-type peridotites except carbonaceous chondrites, and in lunar mare basalts



Locality: Campo Formoso ultramafic complex, Bahia, Brazil
Chromite in octahedral crystals

Origin: Onverwacht, Eastern Bushvel, RSA
Sample size: 3 x 5 cm

Massive black chromite in serpentine matrix
Origin: Psonas, Euboea Island, Greece
Sample size: 4.5 x 6.5 cm



Origin: Clear Creek area, New Idria District, San Benito Co., California, U.S.A.
Sample size: 5.7 x 4.9 x 4.1 cm

Massive black chromite in serpentine matrix
Origin: Psonas, Euboea Island, Greece
Sample size: 4.5 x 6.5 cm

ChromferideFe3Cr

Chromium	11.04 %	Cr
Iron	88.96 %	Fe
	100.00 %	

Ferchromide Cr3Fe

Chromium	87.47 %	Cr
Iron	12.53 %	Fe
	100.00 %	

Table – 1 : WORLD RESOURCES OF CHROMITE

(By principal countries) (in ‘000 tonnes)

Countries	Resource base (in excess of recoverable reserves) 1998	Resource base 2004
South Africa	550,0000	2,00,000
Kazakh Stan	32,0000	47,000
Zimbabwe	93,0000	-
Finland	12,0000	-
India *	17770 *	5,700 **
Brazil	23000	-
Turkey	20000	-
United States	10,000	7,000
Albania	6100	-
Iran	2400	-
Russia	46,0000	-
Other Countries	37000	11,00,000
World total	**750,0000**	**18,0000**

[Source : U.S.G.S. Mineral Commodity Summaries, 1998, 2004]

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WORLD RESOURCES AND PRODUCTION

The huge deposits of South Africa, constituting more than 75% of known world resources, are now the major sources of chromite ore globally.

The important countries where considerable reserves of chromite ore are known and mined for production of ferro-chrome and charge-chrome etc. are Brazil, Republic of South Africa, Kazakhstan, India, Russia and Finland. Internationally,

79% consumption of chromite made in metallurgical industry, 13% in chemical industry and 8% in refractory industry, on an average. In the metallurgical industry, 60% is consumed for stainless steel productions

Table-II : WORLD PRODUCTION OF CHROMITE (By Principal Countries)

(in '000 tonnes)

Country	2001	2002	2003
Brazil	300	200	300
Finland	575	566	549
India	1549	3066	3199
Iran	-	-	-
Kazakhstan	2046	2370	2928
Russia	-	-	-
South Africa	5502	6439	7405
Turkey	455	326	229
Zimbabwe	723	726	666
Other countries	850	807	1124
World total	**12000**	**14500**	**16400**

GEOLOGY AND DISTRIBUTION OF INDIAN CHROMITE DEPOSITS

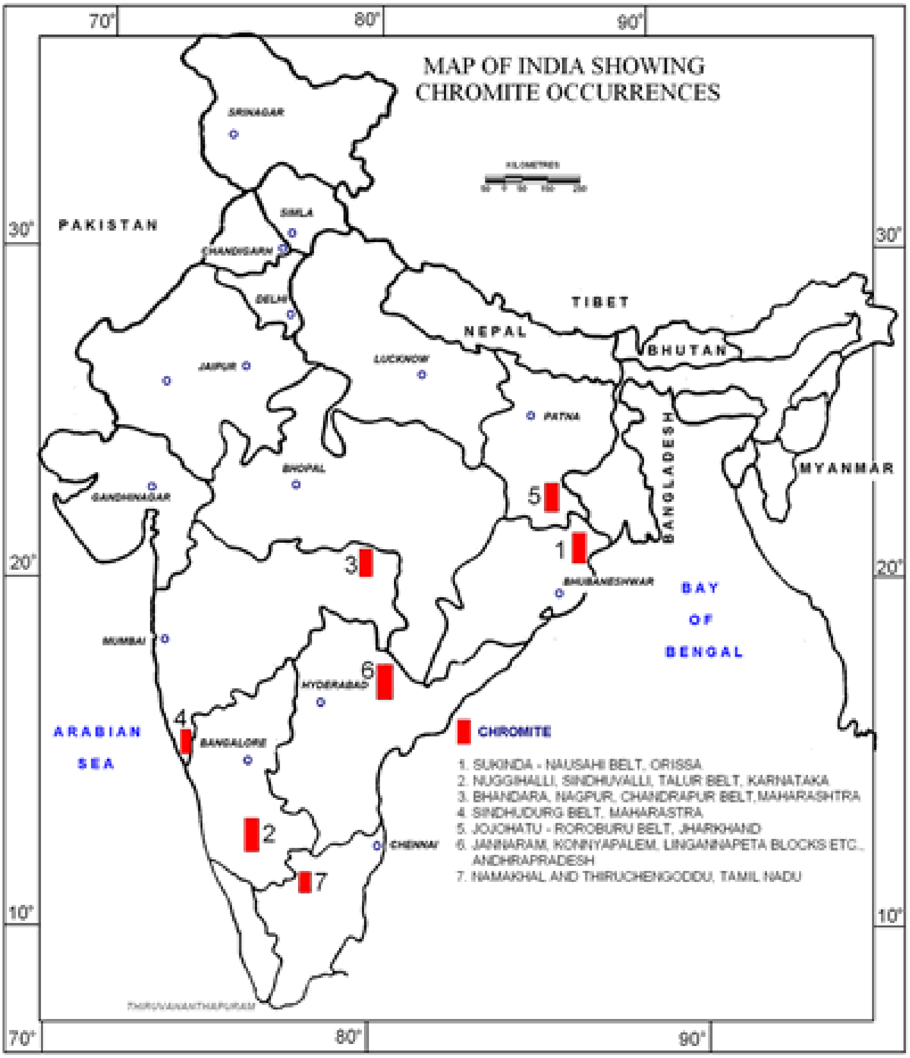
- ***Archaean Greenstone Association:*** **Sukinda and Baula-Nausahi in Orissa, Sinduvalli and Byrapur in Karnataka, Bhandara – Napur belt, Sindhudurg belt and Chandrapur belt in Maharashtra, Roro and Jojohatu in Jharkhand , Ponda-Dudsagar area in Goa.**

- ***Proterozoic Granulite Association:*** **Kondapalli in Andhra Pradesh, Sitampundi complex of Tamil Nadu.**

- ***Mesozoic Ophiolite Association:*** **Chromite occurrences in Manipur, Nagaland, Andaman & Nicobar Islands and Jammu & Kashmir.**

Major share (98.6%) of chromite resources in the country is located in Orissa. The chromite deposits occur in number of localities along NE-SW belt associated with ultramafic complexes of Sukinda, Baula-Nausahi and similar occurrences of ultramafic rocks at Bhalukasoni and Ramgiri.

- Chromite deposits of Sukinda and Katpal ultramafic belt of Cuttack and Dhenkanal districts, Orissa constitutes 95% of the country’s chromite resources. Here chromite with nickel ore occurs as concentration and disseminations in the ultramafic rocks, in the form of lenses, pockets, thin seams and stringers.
- Chromite deposits of Nausahi in Keonjhar district, Orissa occur in band and lenses within serpendine, peridotite, pyroxenite, gabbro, Vanadiferous magnetite and anorthosite resembling well known stratiform of world
- Other states contributing to the country’s resources of chromite are Manipur, Karnataka, Jharkhand, Maharashtra, Tamil Nadu and Andhra Pradesh.
- In Manipur, chromite is associated with serpentine.
- In Karnataka, the ultramafic rocks bearing chromite occur in two belts; viz Nuggehalli, Arsikhera and Nanjangud in Mysore district.
- In Maharashtra, it occurs in altered ultramafic rocks.
- In Andhra Pradesh, it occurs in Eastern Ghat group of rocks in Khammam and Krishna district.
- In Tamil Nadu, chromite associated with amphibolites bands are found in Sitampundi complex of anorthosites.
- In Nagaland, nickeliferrous chromite has been located in ultramafic belt.
- The major chromite resources are from Sukinda followed by Baula-Nausahi area of Orissa.
- Small resources have been established in Karnataka, Maharashtra and Jharkhand

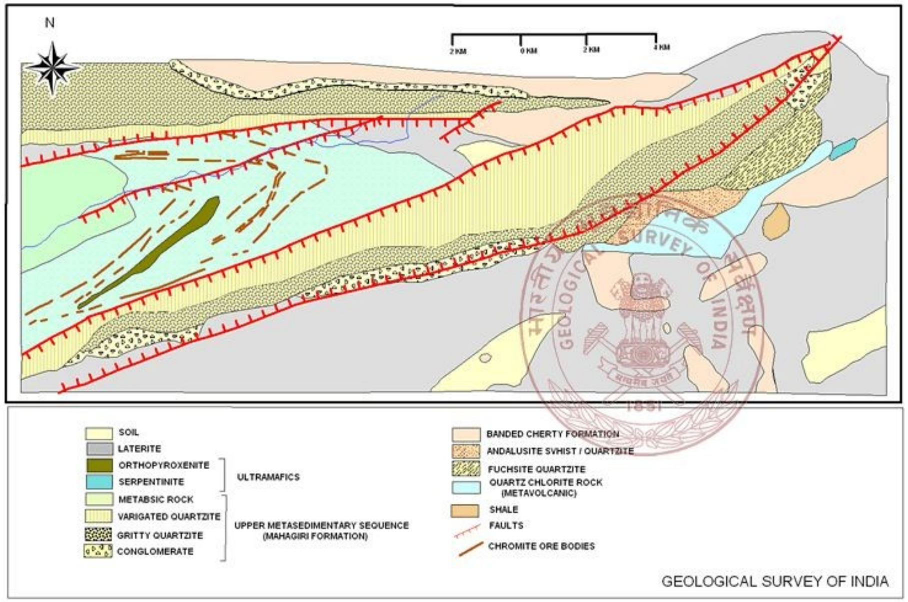


MAP OF INDIA SHOWING CHROMITE OCCURRENCES

1. SUKINDA - NAUSAHI BELT, ORISSA
2. NUGGIHALLI, SINDHUVALLI, TALUR BELT, KARNATAKA
3. BHANDARA, NAGPUR, CHANDRAPUR BELT, MAHARASHTRA
4. SINDHUDURG BELT, MAHARASTRA
5. JOJOHATU - ROROBURU BELT, JHARKHAND
6. JANNARAM, KONNYAPALEM, LINGANNAPETA BLOCKS ETC., ANDHRAPRADESH
7. NAMAKHAL AND THIRUCHENGODDU, TAMIL NADU

PLATE NO 4

GEOLOGICAL MAP OF SUKINDA CHROMITE BELT, CUTTACK DISTRICT, ORISSA

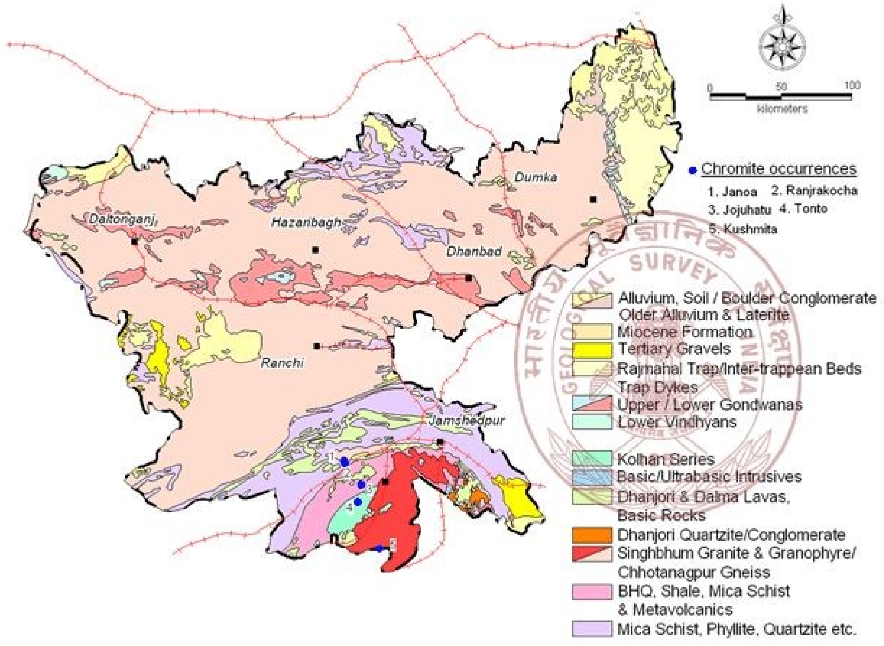


GEOLOGICAL SURVEY OF INDIA

Geological Survey of India

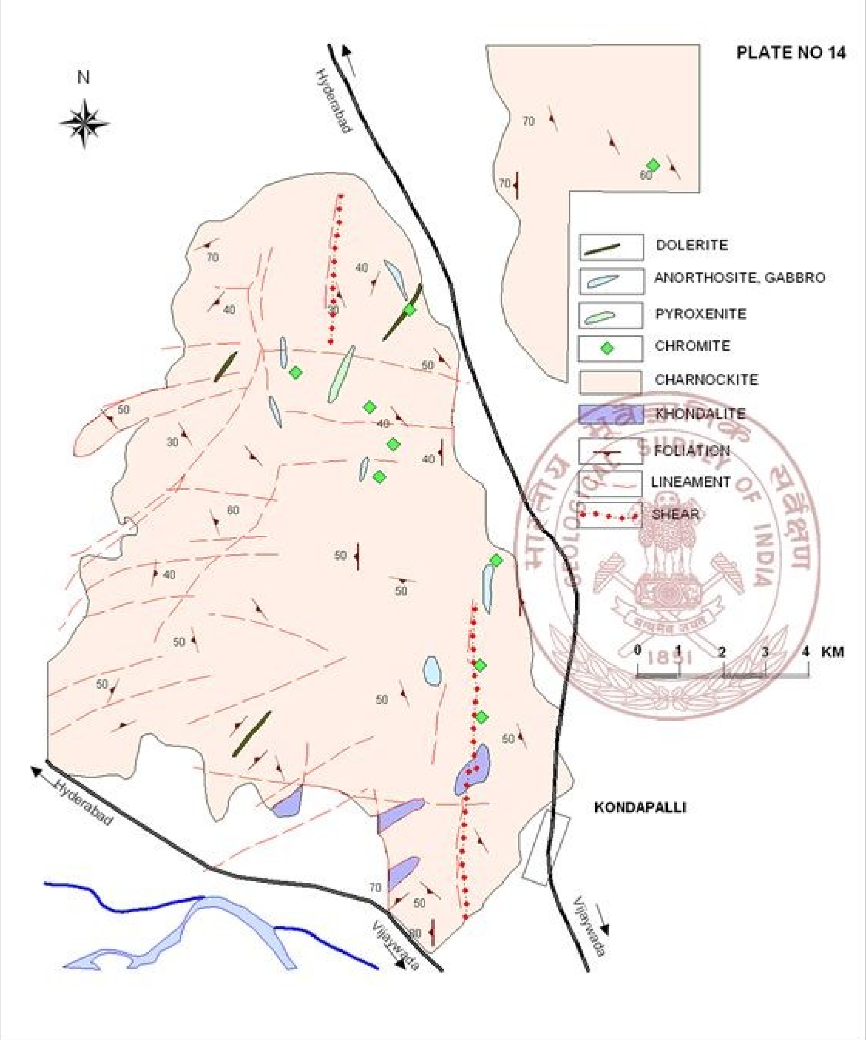
PLATE NO. 6

GEOLOGICAL MAP OF JHARKHAND SHOWING CHROMITE OCCURRENCES

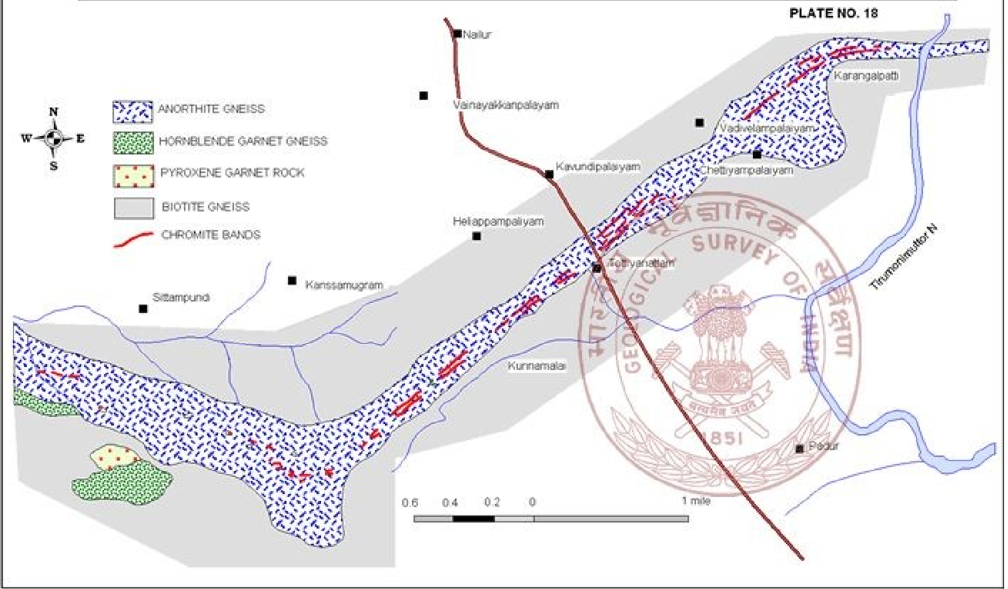


Geological Survey of India

GEOLOGICAL MAP SHOWING STRUCTURAL TRENDS & CHROMITE OCCURRENCES IN KONDAPALLI HILLS, KRISHNA DISTRICT, ANDHRA PRADESH

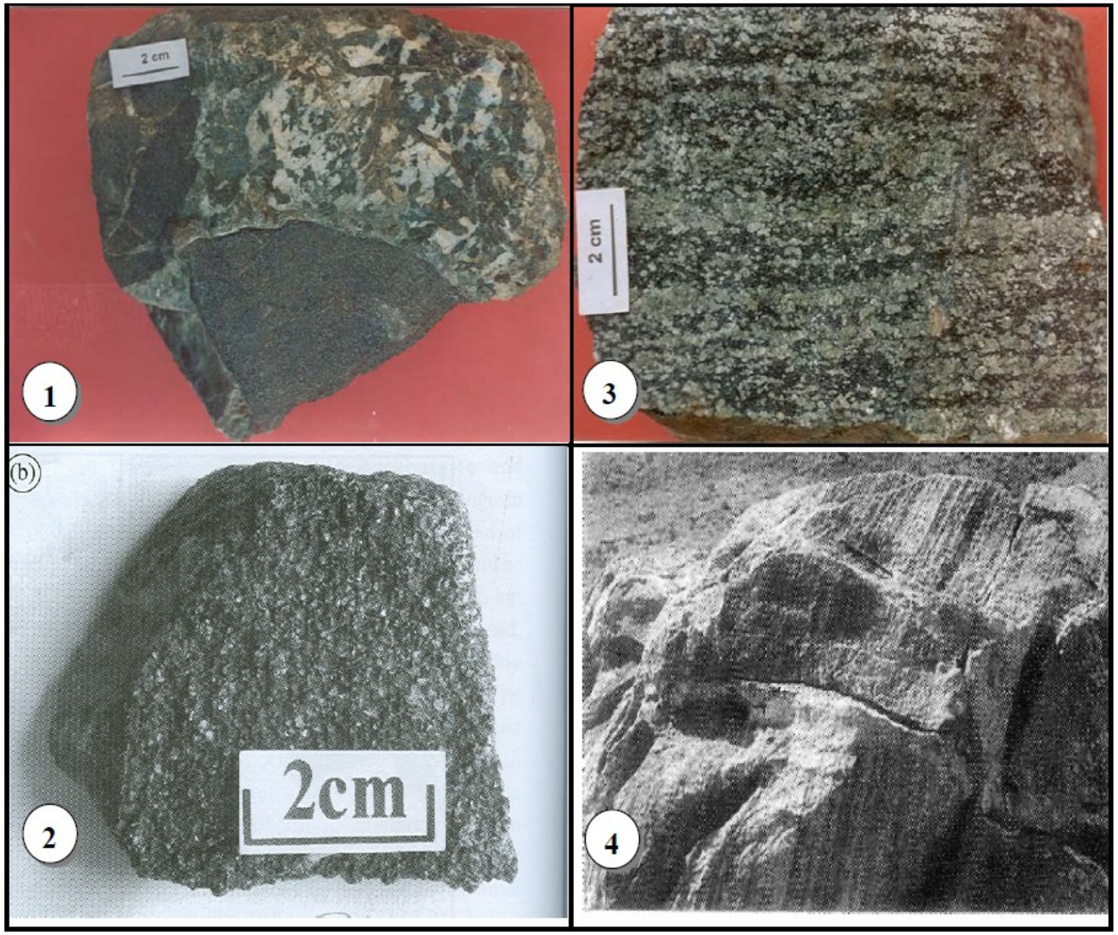


CHROMITE DEPOSITS, NAMAKKAL AND TIRUCHENGODU TALUKS, SALEM DISTRICT, TAMIL NADU

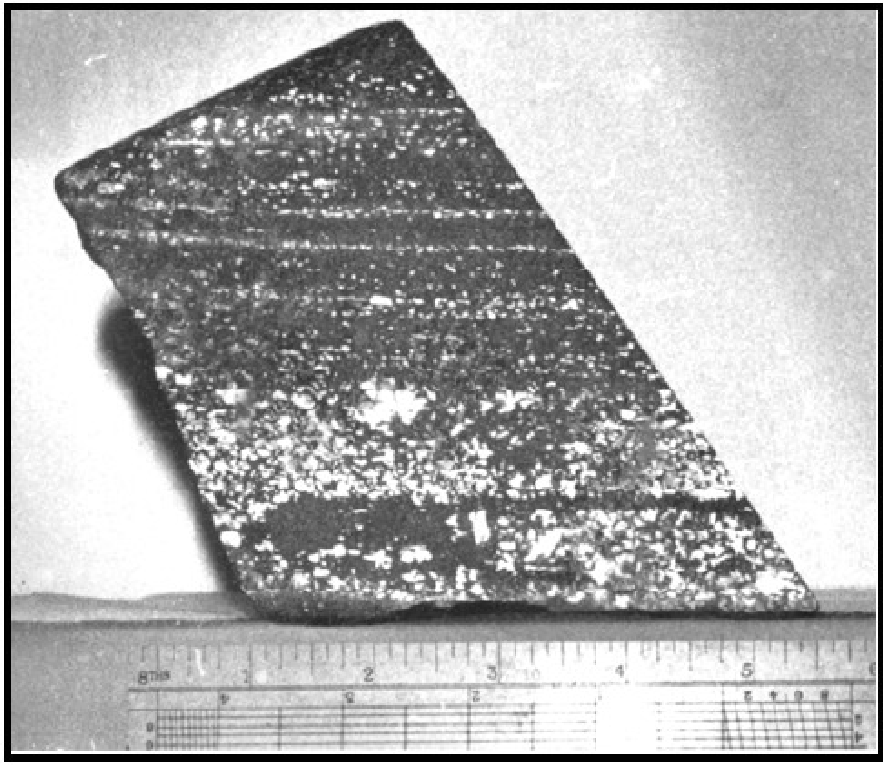


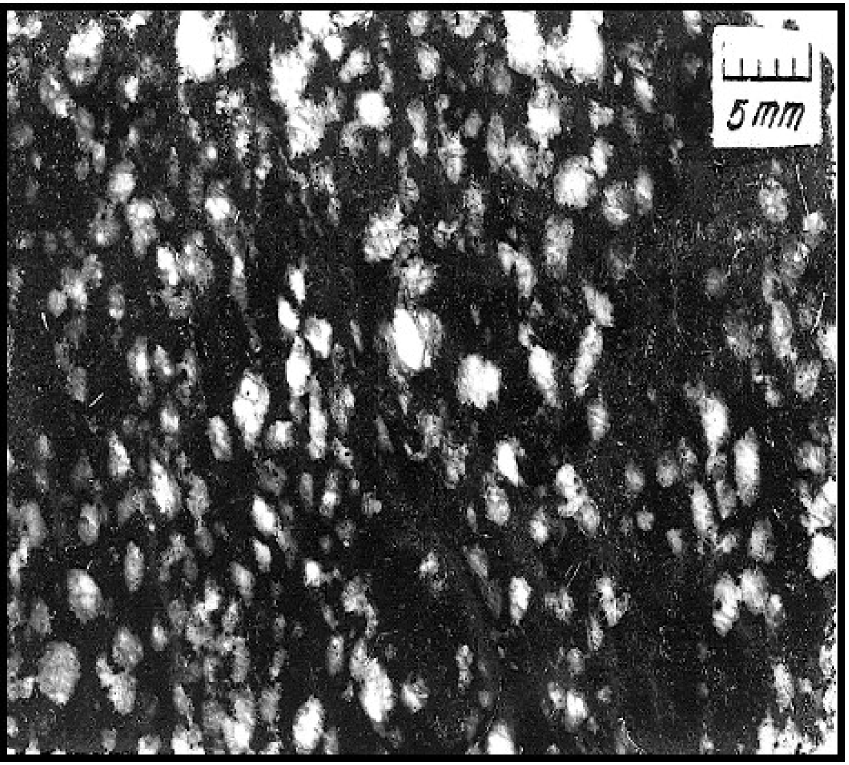
Structures and Textures of Indian chromites:

Plate 2: Meso-scale structures



1. Massive chrome ore included in the gabbro of the brecciated zone collected from sub surface Bangur mine of Orissa Mining Corporation.
2. Granular chromite ore from Roro-Jojohatu
3. Banded chrome ore showing crude layering of chromite and altered peridotite collected from a quarry in Nuasahi mines of IMFA.
4. Field photograph of well preserved mm scale rhythmic banding displayed by Rangapura ultramafic body, Karnataka. Dark bands correspond to chromitite and the light bands to serpentinised dunite-peridotite.





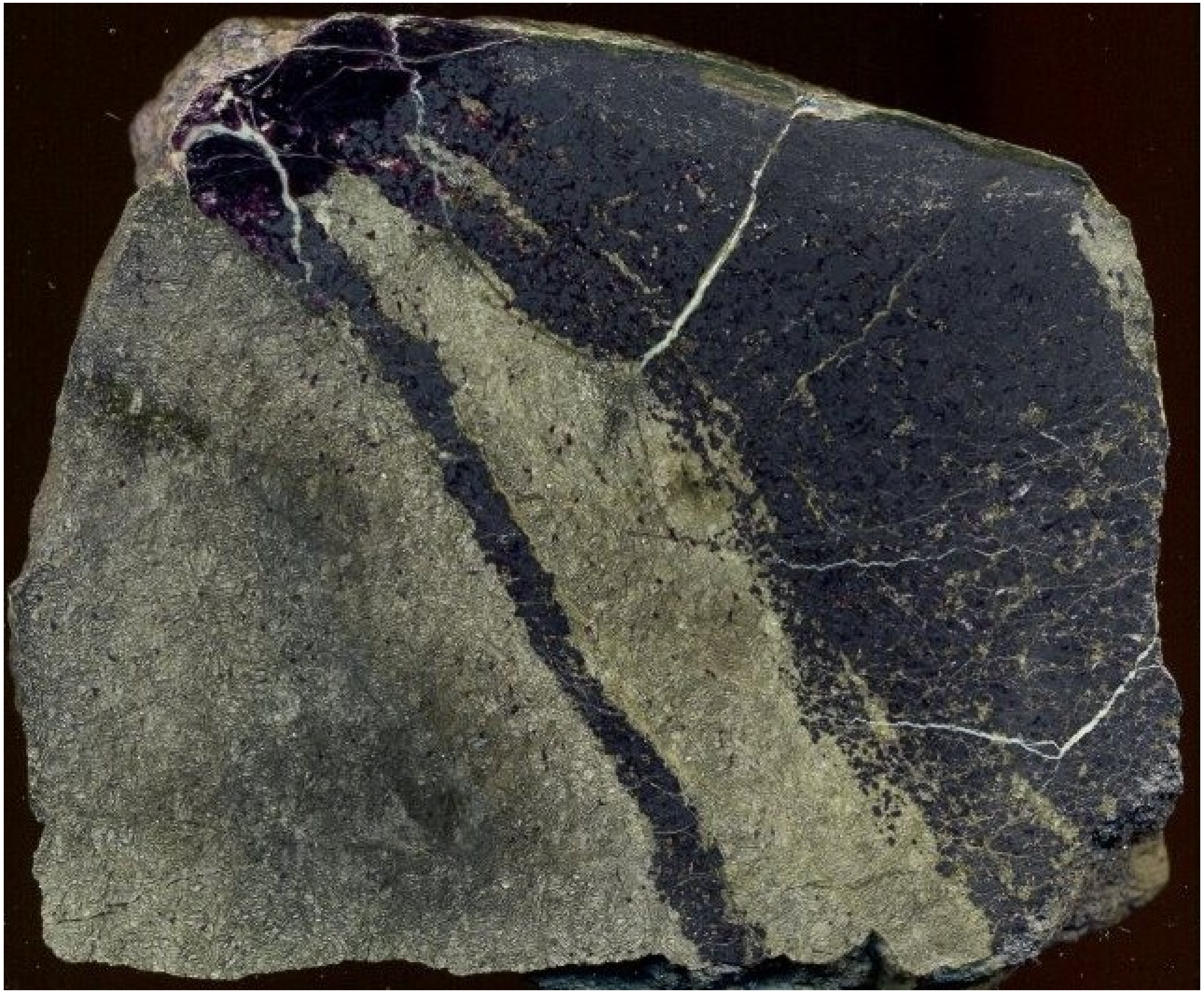
5. Small scale slump structure in rhythmically layered chromitite of TISCO mines, Grade-1 quarry.

6. Disseminated chrome ore from a bore hole in Kalarangi chromite mine of Orissa Mining Corporation (OMC).

Igneous breccia containing chromite clasts (view approximately 16 m high) (Boula, Orissa, India).

MINING & PRODUCTION

- The production of chromite at 4799 thousand tonnes during 2007-08 is decreased by 9 % as compared to that in the previous year owing to decrease in market demand.
- The number of reporting mines was 21 in both the years.
- Six principal producers operating 12 mines together accounted for 90% of the total production during the year.
- The contribution of 13 mines, each producing more than 10000 tonnes per annum was 99.70 % of the total production.
- The share of public sector in total production was 30% in 2007-08 as compared to that of 31% in the previous year.
- About 30% of the total production was reported from captive mines in current year as compared to that 26% in the previous year.



Locality: Kraubath, Leoben, Styria, Austria
Chromite in partly serpentinized dunite, upper left some chromian clinochlore.
Polished slab,

Locality: Augraben, Kraubath, Leoben, Styria, Austria
Black chromite grains in serpentinite matrix.
Width of the picture:15mm

Locality: Caledonia Mine, Holguín Province, Cuba
Black nodular chromite in matrix.

Locality: Finero Ultramafic Complex, Different Municipalities, Verbano-Cusio-Ossola Province, Piedmont, Italy Cromite crystals in peridotite.

End use Grade classification

1	Ferro-Chrome	Cr_2O_3 48% (min), Cr:Fe ratio 2.8:1 (min)
2	Charge-Chrome	Cr_2O_3 44% (min), Cr:Fe ratio 1.6:1 (min)
3	Refractory	Cr_2O_3 +40%, FeO 18% (max), SiO_2 12% (max), MgO 15% (max), physical - lumpy
4	Chemical	Cr_2O_3 44% (min), FeO 20% (max), Al_2O_3 14% (max), SiO_2 7% (max), CaO 3% (max), MgO 14% (max)
5	Beneficiable	Cr_2O_3 12% (min)

MINING & PRODUCTION

- Chromite is mined mostly by opencast method in the country.
- M/S TISCO is operating open cast mine at Sukinda.
- M/s OMC has open cast chromite mines at South Kaliapani, Kaliapani, Sukrangi, Kalarangi,Kathpal and Bangur in Orissa.
- Other open cast mines are Ostopal of M/s FACOR, Suruabil of M/s Mishrilal Jain, Kamarda of M/s B. C. Mohanty, Chingudipal and Sukinda of M/s IMFA, Tailangi of M/s IDCOL and Bangur of M/s ICCL.
- OMC is also developing underground mine near Bangur, in Baula-Nausahi chromite belt.
- Underground mines are confined to Byrapur of M/s MML in Karnataka and Boula and Kathpal mines (both underground and open cast) of M/s FACOR and Nuasahi of M/s IMFA (underground development was going on) in Orissa.
- In Sukinda area, deposits of chromite lying below 100 m depth may have to be exploited by highly specialized underground mining techniques.
- M/s Mysore Mineral Ltd. is mining chromite ore in Hassan District, Karnataka.
- Out of the existing six leases, two are underground mines (Byrapur chromite mines) and the rest four leases namely, Thagdur, Jambur, Bhakhtahalli, Aldahalli, opencast method in working is practiced.

Great intrusive body with 530km length, The Great Dyke, Zimbabwe

Great Dyke, ZIMBABWE

ASTER/VNIR, RGB=321 (2000/10/16) METI/ERSDAC

The image shows Archeozonic mafic dyke in Zimbabwe (approx. 2.46billion years). The great dyke is 3-12km wide and stretches out 530km from north-northeast to south-southwest, crossing the whole southern Zimbabwe region. The image focuses on 80km at the southern edge.

In the image, a few faults can be observed across the great dyke, of which the most peculiar right lateral fault at the upper part from northwest to southeast direction, causing the dyke to slide by a few kilometers. A river runs along the fault.

Valuable metal deposits including platinum and chrome are distributed all over the great dyke, providing an important source of income for the country's economy.

NON-FEROUS AND ALLIED METALS

COPPER

Copper, the pinkish coloured and comparatively softer metal, is well known to all of us. It is one of the few metals to occur in native metal form as nuggets and masses in nature and is being used prior to iron by mankind since ancient past. Hence, it is the metal that has high cultural significance.

On record this metal was known to some of the oldest civilizations and has a history of use that is at least 10,000 years old. A copper pendant was found in what is now northern Iraq that dates to 8700 BC. Evidence of regular use of copper artifacts also came from Mehrgarh in Baluchistan (earlier part of India) datable to 6500 BC.

Use of copper compounds also dates back to before 4000 BC. In the past it was also used in making mirror.

The archaeological studies made on the basis of excavations at Ganeshwar, an old mining town located east of Khetri in north Rajasthan (India), ascribe the earliest Indian copper mining to Indus valley civilization (3000-1500 BC). Large number of the ancient copper mining and metallurgical sites (slag heaps) present in almost all States of the country bear testimony to it. In Kumaun (central Himalaya) copper smithy is considered an old traditional technology.

Mention of copper mining and metallurgy in country exists in several ancient works e.g. Kautilya's Arthsastra (3rd Century BC) to Ain-i-Akbari in 1590 AD.

The Faynan district of Jordan is known for its rich copper ore deposits. A three thousand-year-old industrial scale metal production operation in the region is now being touted as "King Solomon's mines." Photograph by Kenneth Garrett.

During the ancient period 'native copper' was the initial source of this metal until it was possible to extract copper from its ores, which are far more abundant in nature and, therefore, form the main source of copper today.

Copper possesses some of very special characters such as excellent ductility, high conductivity of heat and electricity, resistance to corrosion, ability to form alloys with other metals and beauty. It is completely soluble with gold. Its length can be increased as much as 5,000 times. Hence, it is an ideal metal for making wire.

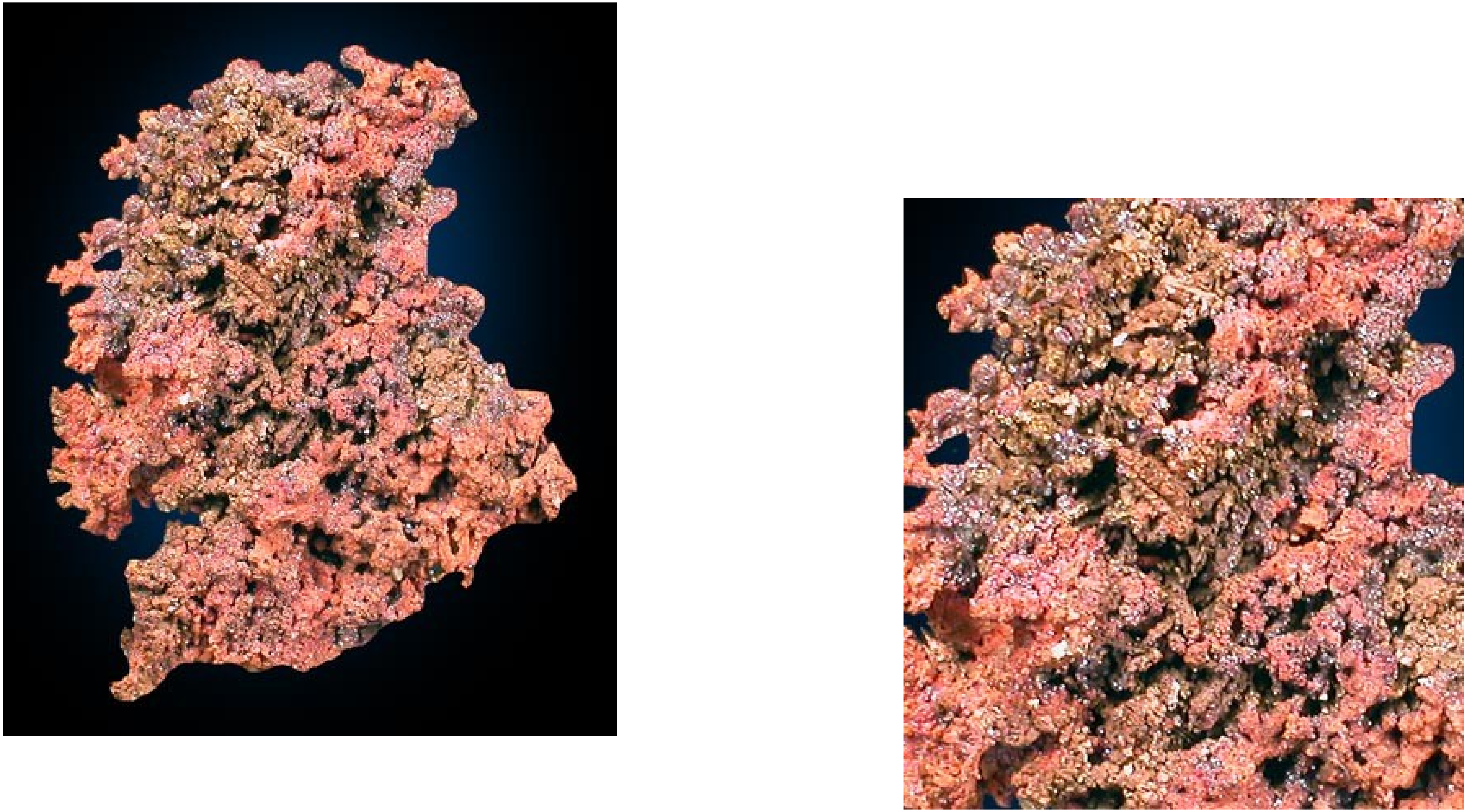
Copper has 29 distinct isotopes ranging in atomic mass from 52 to 80. Two of these, 63Cu and 65Cu, are stable and occur naturally, with 63Cu comprising approximately 69% of naturally occurring copper. The other 27 isotopes are radioactive and do not occur naturally. The most stable of these is 67Cu with a half-life of 61.83 hours

When found in free metallic state it is called 'native copper' forming polycrystalline mass, wire, distorted crystals, grains etc. In nature it occurs in mineral form. It forms a primary mineral in basalts, the volcanic rocks.

It's most common mineral forms are sulphides, carbonates and oxides. Copper constitutes 70 parts per million of the Earth's crust and is present to the extent of 0.020-0.001 parts per million in seawater.

NATIVE COPPER

Copper in calcite



Crystallized loose grouping of native copper partly encrusted by tiny red cuprite crystals

Copper altering to malachite

COPPER SULPHIDE ORE

Copper Ore	Color	Opacity/ Lustre/ streak	Hardness / SG Low/ SG High	Cleavage / Fracture	Habit
Chalcopyrite CuFeS2 Tetragonal	Brass-yellow, tarnishes iridescent	Opaque Metallic Greenish black	3.5-4 4.35 4.35	{011} sometimes distinct Uneven; brittle	Crystals sphenoidal, resemble tetrahedrons; massive, compact; reniform, botryoidal
Bornite Cu5FeS4 Cubic	Copper-red or bronze,	Opaque Metallic Light grayish black	3.3 5.079 5.079	{111} in traces Conchoidal to uneven	Crystals cubic, octahedral or dodecahedral, rare; massive, granular
Chalcocite Cu2S Monoclinic	Blackish gray to black	Opaque Metallic Blackish gray	2.5-3 5.5 5.8	{110} indistinct Conchoidal; brittle, somewhat sectile	Crystals pseudohexagonal prisms formed by twinning; short prismatic or thick tabular; massive
Covellite CuS Hexagonal	Light to dark indigo-blue	Opaque Submetallic to dull Shining gray-black	1.5-2 4.681 4.681	{0001} perfect Uneven; brittle, thin laminae flexible	Crystals thin tabular hexagonal plates; massive, foliated
Enargite Cu3AsS4 Orthorhombic	Grayish black to iron-black	Opaque Metallic Grayish black	3 4.45 4.45	{110} perfect, {100} and {010} distinct, {001} indistinct Uneven; brittle	Crystals prismatic or tabular; massive, granular or prismatic
Tetrahedrite (Cu,Fe)12Sb4S13 Cubic	Steel-gray to iron-black	Opaque, Metallic, Black to brown to dark red	3-4.5 4.6 5.1	Empty Subconchoidal to uneven; brittle	Crystals tetrahedral, modified, contact penetration twins; massive, coarse granular to compact

COPPER OXIDE ORE

Copper Ore	Color	Opacity/ Lustre/ streak	Hardness / SG Low/ SG High	Cleavage / Fracture	Habit
Cuprite Cu2O Cubic	Red, brownish red, purplish red to almost black	Transparent to translucent Adamantine or submetallic to earthy Brownish red, shining	3.5-4 6.14 6.14	{111} interrupted, {001} rare Conchoidal to uneven; brittle	Crystals cubic, octahedral or dodecahedral; hair-like forming wads or mats (chalcotrichite); massive, compact, granular
Malachite Cu2(CO3)(OH)2 Monoclinic	Bright green to dark or blackish green	Translucent to opaque Vitreous to adamantine Pale green	3.5-4 4.05 4.05	{201} perfect, {010} fair Subconchoidal to uneven; crystals brittle; massive material tough	Crystals acicular or short to long prismatic, wedge-shaped terminations, small; massive; compact crusts; botryoidal
Azurite Cu3(CO3)2(OH)2 Monoclinic	Light blue to very dark blue, usually azure blue	Transparent to nearly opaque Vitreous Blue, lighter than color	3.5-4 3.77 3.77	{011} slightly imperfect; {100} fair; {110} in traces Conchoidal; brittle	Crystals varied in habit and often modified; tabular or short prismatic, equant or rhombohedral; massive, stalactitic, earthy, nodular concretions

COPPER silicate and native ORE

Copper Ore	Color	Opacity/ Lustre/ streak	Hardness / SG Low/ SG High	Cleavage / Fracture	Habit
Chrysocolla Cu2H2Si2O5(OH)4 Monoclinic	Green, bluish green, blue	Transluscent Vitreous, greasy, dull White to pale blue or green	2-4 2 2.2	None Uneven to conchoidal	Reniform, botryoidal masses
Copper, Cu Cubic Native	Copper-red, brown; pale rose when fresh, pale pink	Opaque Metallic Pale red	2.5-3 8.94 8.94	Empty Hackly; malleable and ductile	Crystals cubic, octahedral, dodecahedral, tetrahexahedral; arborescent, wirelike, massive, powdery

Chalcopyrite

Chemical Formula: $CuFeS2$

Iron 30.43 % Fe, Copper 34.63 % Cu, Sulfur 34.94 % S

Common in sulfide veins and disseminated in igneous rocks.

Well-formed crystals of chalcopyrite and quartz.

Cleavage: {112} Indistinct

Color: Brass yellow, Honey yellow.

Density: 4.1 - 4.3, Average = 4.19

Diaphaneity: Opaque

Fracture: Brittle - Generally displayed by glasses and most non-metallic minerals.

Hardness: 3.5

Luminescence: Non-fluorescent.

Luster: Metallic

Magnetism: Magnetic after heating

Streak: greenish black

Bornite (Cu5FeS4)

Iron 11.13 % Fe,Copper 63.31 % Cu, Sulfur 25.56 % S

Disseminated in igneous intrusions and a primary and secondary mineral in copper ore veins

Cleavage: {111} Imperfect
Color: Copper red, Bronze brown, Purple.
Density: 4.9 - 5.3, Average = 5.09
Diaphaneity: Opaque
Fracture: Conchoidal - Fractures developed in brittle materials characterized by smoothly curving surfaces, (e.g. quartz).
Habit: Granular - Generally occurs as anhedral to subhedral crystals in matrix. Massive - Granular - Common texture observed in granite and other igneous rock. Reniform - "Kidney like" in shape (e.g.. hematite).
Hardness: 3 - Calcite
Luminescence: Non-fluorescent.
Luster: Metallic
Magnetism: Magnetic after heating
Streak: grayish black

Bornite (Cu5FeS4)

Chalcocite (CU2S)

Copper 79.85 % Cu, Sulfur 20.15 % S

Cleavage: {110} Indistinct

Color: Blue black, Gray, Black, Black gray, Steel gray.

Density: 5.5 - 5.8, Average = 5.65

Diaphaneity: Opaque

Fracture:Conchoidal

Habit: Euhedral Crystals - Occurs as well-formed crystals showing good external form. Granular - Generally occurs as anhedral to subhedral crystals in matrix. Massive - Uniformly indistinguishable crystals forming large masses.

Hardness: 2.5-3 - Finger Nail-Calcite

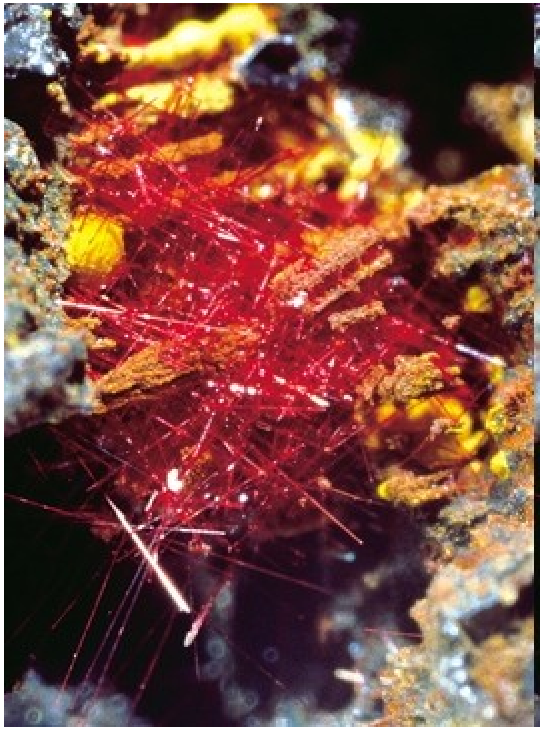
Luminescence: Non-fluorescent.

Luster: Metallic

Magnetism: Nonmagnetic

Streak: grayish black

Cuprite Cu_2O Copper 88.82 %, Oxygen 11.18 %



Cleavage: {111} Imperfect

Color: Brown red, Purple red, Red, Black.

Density: 6.1

Diaphaneity:Transparent to translucent

Fracture: Brittle - Conchoidal - Very brittle fracture producing small, conchoidal fragments.

Habit: Capillary - Very slender and long, like a thread or hair (e.g. millerite).

Habit: Massive - Granular - Common texture observed in granite and other igneous rock.

Hardness: 3.5-4 - Copper Penny-Fluorite

Luminescence: Non-fluorescent.

Luster: Adamantine

Magnetism:Nonmagnetic

Streak: brownish red

Dark red ball or sphere of cuprite crystals set on a pearly white dolomite crystal matrix.

Malachite Cu2(CO3)(OH)2

Secondary mineral in the oxidized zones of copper ore deposits

Cleavage:{201} Perfect, {010} Fair

Color: Green, Dark green, Blackish green.

Density: 3.6 - 4, Average = 3.8

Diaphaneity:Translucent to subtranslucent to opaque

Fracture: Uneven - Flat surfaces (not cleavage) fractured in an uneven pattern.

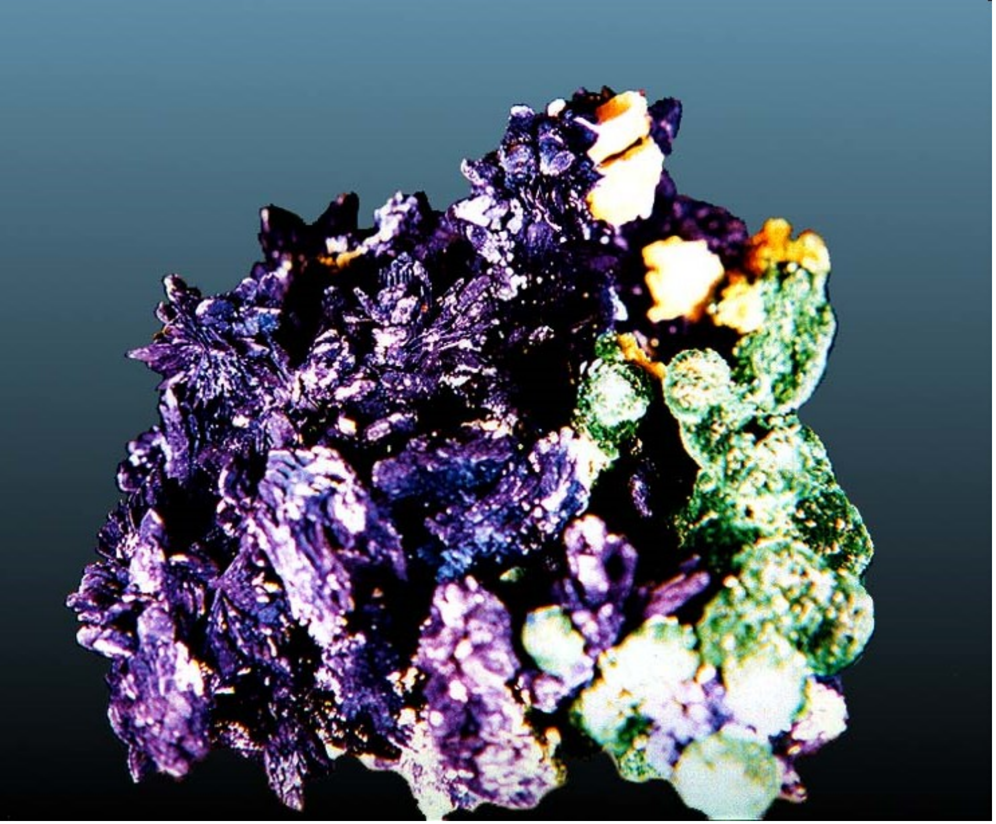
Habit: Botryoidal - "Grape-like" rounded forms (e.g.. malachite). Massive - Fibrous - Distinctly fibrous fine-grained forms. Stalactitic - Shaped like pendant columns as stalactites or stalagmites

Hardness: 3.5-4

Luminescence: Non-fluorescent.

Luster: Vitreous - Silky

Streak: light green



Dark blue stubby pyramidal azurite crystals and green botryoidal-shaped radial aggregates of malachite.

Botryoidal malachite

Azurite Cu3(CO3)2(OH)2

Cleavage: {011} Perfect, {100} Fair

Color: Azure blue, Blue, Light blue, Dark blue.

Density: 3.77 - 3.89, Average = 3.83

Diaphaneity: Transparent to subtranslucent

Fracture: Brittle - Conchoidal

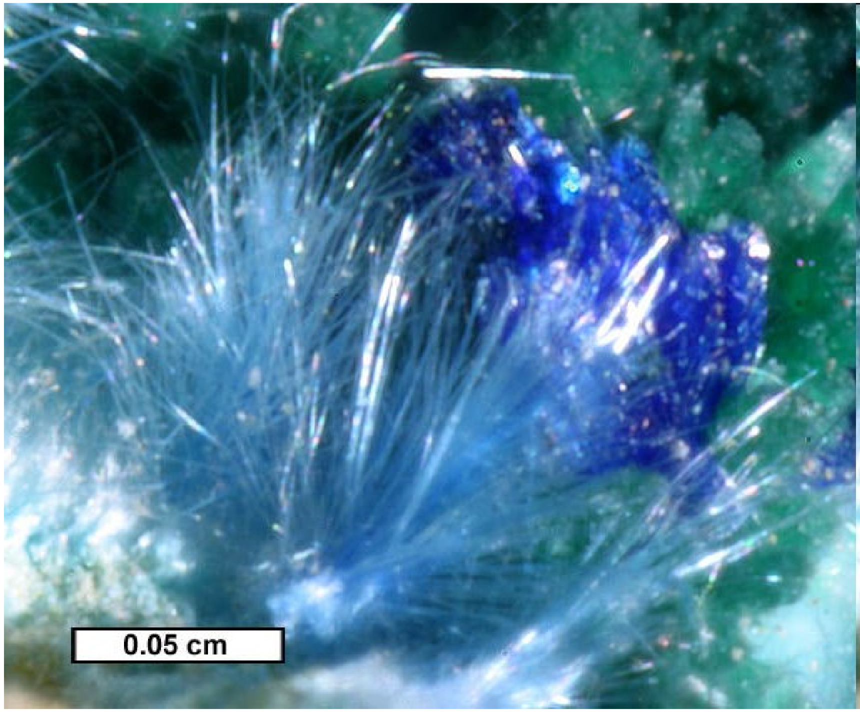
Habit: Prismatic - Crystals Shaped like Slender Prisms (e.g. tourmaline). Stalactitic - Shaped like pendant columns as stalactites or stalagmites. Tabular - Form dimensions are thin in one direction.

Hardness: 3.5-4 - Copper Penny-Fluorite

Luminescence: Non-fluorescent.

Luster: Vitreous (Glassy)

Streak: light blue



Blue, hairy crystals of cyanotrichite with dark-blue, blocky azurite on a green, malachite matrix

Azurite with malachite

Copper-bearing ores fall into three main classes i.e. oxide, carbonate and the sulfide. There are more than 150 ore minerals of copper.

The important oxide ores include cuprite ($\mathrm{Cu2O}$) and tenorite (CuO).
The carbonate ores are malachite ($\mathrm{Cu2CO3(OH)2}$) and azurite ($\mathrm{Cu3(CO3)2(OH)2}$).

The common sulfides of copper include chalcopyrite ($\mathrm{CuFeS2}$), covellite (CuS), chalcocite ($\mathrm{Cu2S}$) and bornite ($\mathrm{Cu5FeS4}$).

Fresh copper sulphides form deeper parts of the ore zones or lodes, which are not exposed to weathering. Near the surface, these get altered by oxidation and other chemical actions to native metal, oxides and carbonates.

These secondary copper minerals also form rich ore and owing to characteristic green or blue colour, even small amounts of copper ore is identified easily in the rocks.

Cuprite is a secondary mineral, which forms in the oxidized zone of copper sulfide deposits. It has a relatively high specific gravity of 6.1; and is also known as ‘ruby copper’ due to its distinctive red color. The tenorite is dull grey-black colored mineral of copper.

The malachite is a green-colored copper mineral, which crystallizes in the monoclinic system, and most often forms botryoidal, fibrous or stalagmitic masses.

Azurite is a soft, deep blue copper mineral produced by weathering of copper ores. It occurs as massive to nodular, and often stalactitic in form. It tends to lighten in color over time due to weathering into malachite. Both the minerals were used as mineral pigment for centuries.

The chalcopyrite is brassy yellow in colour, shows metallic lustre and tarnishes to iridescent blue, green, yellow and purple. Its hardness is 3.5 to 4 on the Mohs scale and specific gravity 4.2. It breaks with conchoidal fracture and becomes magnetic on heating. When exposed to air, it oxidizes to a variety of oxides, hydroxides and sulfates. Chalcopyrite occurs in a variety of ore types such as huge masses, irregular veins and disseminations. Its streak is diagnostic as green tinged black. Half of the world's copper deposits are in the form of chalcopyrite ore.

The covellite is a rare copper sulfide mineral of indigo blue colour and was the first discovered natural superconductor. It is commonly found as secondary mineral, rarely as a primary mineral, and very rare as volcanic sublimate.

Chalcocite is opaque, dark-gray to black in colour with a metallic lustre. It has a hardness of 2½ - 3 with an orthorhombic crystal system. It is a secondary mineral that forms from the alteration of other minerals; it has been known to form pseudomorphs of different minerals.

Bornite is brown to copper-red in colour on fresh surfaces that tarnishes to various shades of blue to purple. Its striking iridescence gives it nickname ‘peacock ore’. It crystallizes in orthorhombic system and occurs mostly as granular masses and disseminations in different rocks. It has of grayish black streak. It is also magnetic after heating.

Copper ores occur in varied forms viz. in native form as wire, grains, crystals etc., in mineral form as disseminations, veins, stock work etc. in variety of rocks.

Mode of Occurrence and Origin of Copper

Copper occurs in a variety of ways

Magmatic Segregations – Dissiminated forms, veins and lodes

Contact metamorphic deposits – bedded deposits

Porphyry copper deposits – Stocks, chonoliths intrusions of monzonite or diorite porphyry of early Tertiary age

In India, Copper lodes occur mostly in veins, stringers, patches, dissiminated forms, fracture and cleavage fillings, etc. and associated with different types of rocks mostly Dharwar and Cuddapah age

Copper associated with lead, zinc, silver, gold, etc.

Copper deposits mostly originated by hydrothermal solutions

Copper is extracted from its ores by two principal methods i.e. pyrometallurgical and the hydrometallurgical method.

In the first method ore is crushed into powder. Minerals are concentrated into slurry. Copper minerals are separated by flotation. Smelting of concentrate and extraction of metal follow it; by heat, flux and addition of oxygen. Sulfur, iron and other undesirable elements are removed and product is called 'blister copper'. It is further refined by fire and electro-refining methods.

The second method i.e. 'solvent extraction' and 'electro-winning' is most dominant leaching process in use today in recovering copper by chemical solutions. It involves two major stages: solvent extraction - the process by which copper ions are leached or extracted from the ore using chemical agents; and electro-winning - electrolysis of Cu ions plated onto the cathode and thereafter removed in elemental form.

The most common copper-base alloys are the 'bronze' made of copper and tin, and the 'brass' made of copper and zinc. Bronze was the first to be produced by man during ancient period and is of two kinds i.e. wrought bronze and the cast bronze. Alloying it with other elements such as aluminum, silicon, manganese, beryllium, lead etc different types of bronzes are produced, which have different usage. The bronze figure of a dancing girl recovered from Mohenjodaro is a testimony of the knowledge of copper alloying of the Indians during Harappan (Sindhu-Sarasvati) civilization.

Brass is comparatively stronger than bronze; its colour changes with zinc content. German brass looking like gold contains 20 parts zinc in hundred, and is used in making cheaper ornaments by rolling it into thin foils. The naval brass is made of tin, copper and zinc and it strongly resists corrosion in seawater

Copper is one of the oldest metals ever used and has been one of the important materials in the development of civilization. Today it has become a major industrial metal, ranking third after iron and aluminum in terms of quantities consumed.

Copper has been fashioned into ornamental objects and cooking utensils. Coins have been made of copper throughout history. Copper is also used in pigments, insecticides, and fungicides. Electrical uses of copper, including power transmission and generation, building wiring, telecommunication, electrical and electronic products account for about three quarters of total copper usage.

Copper is the third most abundant trace mineral in the body. The human body contains approximately 100-500 mg of copper but it's role is important as it serves as a cofactor for enzymes involved in hemoglobin and collagen formation and is involved in incorporating iron into the structure of hemoglobin. It strengthens blood vessels, bones and nerves.

Copper producing localities in the world are too numerous to mention here. Worldwide famous localities are Broken Hill (Australia); Daye, Hubei Chengmenshan, Jiurui, Jiangxi Province (China); Ogonja (Namibia); and Callington District, Cornwall (England). In addition, Bolivia, Kazakhstan also produce significant amount of copper.

In India, Hindustan Copper Limited (HCL) under Ministry of Mines carries out mining and production of copper. The Company’s mines and plants are spread across four operating Units, one each in the States of Rajasthan, Madhya Pradesh, Jharkhand and Maharashtra i.e. Khetri Copper Complex (KCC) at Khetri Nagar, Rajasthan; Indian Copper Complex (ICC) at Ghatsila, Jharkhand; Malanjkhand Copper Project (MCP) at Malanjkhand, Madhya Pradesh; and Taloja Copper Project (TCP) at Taloja, Maharashtra.

The Khetri Copper Belt, situated in Aravalli Range in Jhunjhunu and Sikar districts, Rajasthan, hosts several copper deposits. The area comprises of tightly folded Proterozoic metasediments that rest over basement gneisses. The prominent copper deposits in the belt are Khetri, Kolihan, Banwas, Chandmari, Dholamala, Akwali and Muradpur-Pacheri. KCC was established in 1967. It has two mechanized underground mines namely 'Khetri' and 'Kolihan' with capacity of 1.0 million tonnes of ore per annum.

It’s ore resources include 26 million tonnes @ 1.13 % Cu at Khetri Mine; 20.64 million tonnes @ 1.35 % Cu at Kolihan Mine; 25.02 million tonnes @ 1.69 % Cu at Banwas Block and 12.10 million tonnes @ 1.03 % Cu at Intervening block.

The Malanjkhand copper belt comprises of a large body of copper ore in granitic rocks. Its prominent deposits include Malanjkhand, Shitalpani, Gidhri Dhorli, Jatta and Garhi Dongri. GSI had initiated systematic explorations for this deposit in 1969. MCP was established in 1982. It has an open pit mine, and concentrator plant. It has 221.00 million tonnes @ 1.31% copper resources at Malanjkhand Mine.

The Singhbhum copper belt of Jharkhand comprises of Proterozoic volcano-sedimentary sequence with a prominent shear zone called Singhbhum shear zone. Copper mineralisation is localized along this shear zone.

Prominent deposits are at Chapri, Rakha, Surda, Kendadih, Pathargora and Dhobani. A British company established the ICC LTD in 1930 at Ghatsila. It was merged with HCL in 1972. It has a cluster of underground copper mines, concentrator plant and smelter. Its operating mine is Surda having 26 MT of ore @ 1.20% Cu. Additional reserves include 47.19 million tonnes @ 0.97% copper at Rakha mine; 12.85 million tonnes @1.73% copper at Kendadih Mine; 63.50 million tonnes @1.14% copper at Chapri Block. The Taloja copper project, set up in 1990, has a plant to produce mainly copper rods (CCR) with ore input from HCL mines. The capacity for the production of primary copper in India has risen from a mere 47,500 t/pa till 1997 to 9,47,000 tonne in 2008-09, with the result that India is now a net exporter of refined copper.

COPPER ORE IN INDIA

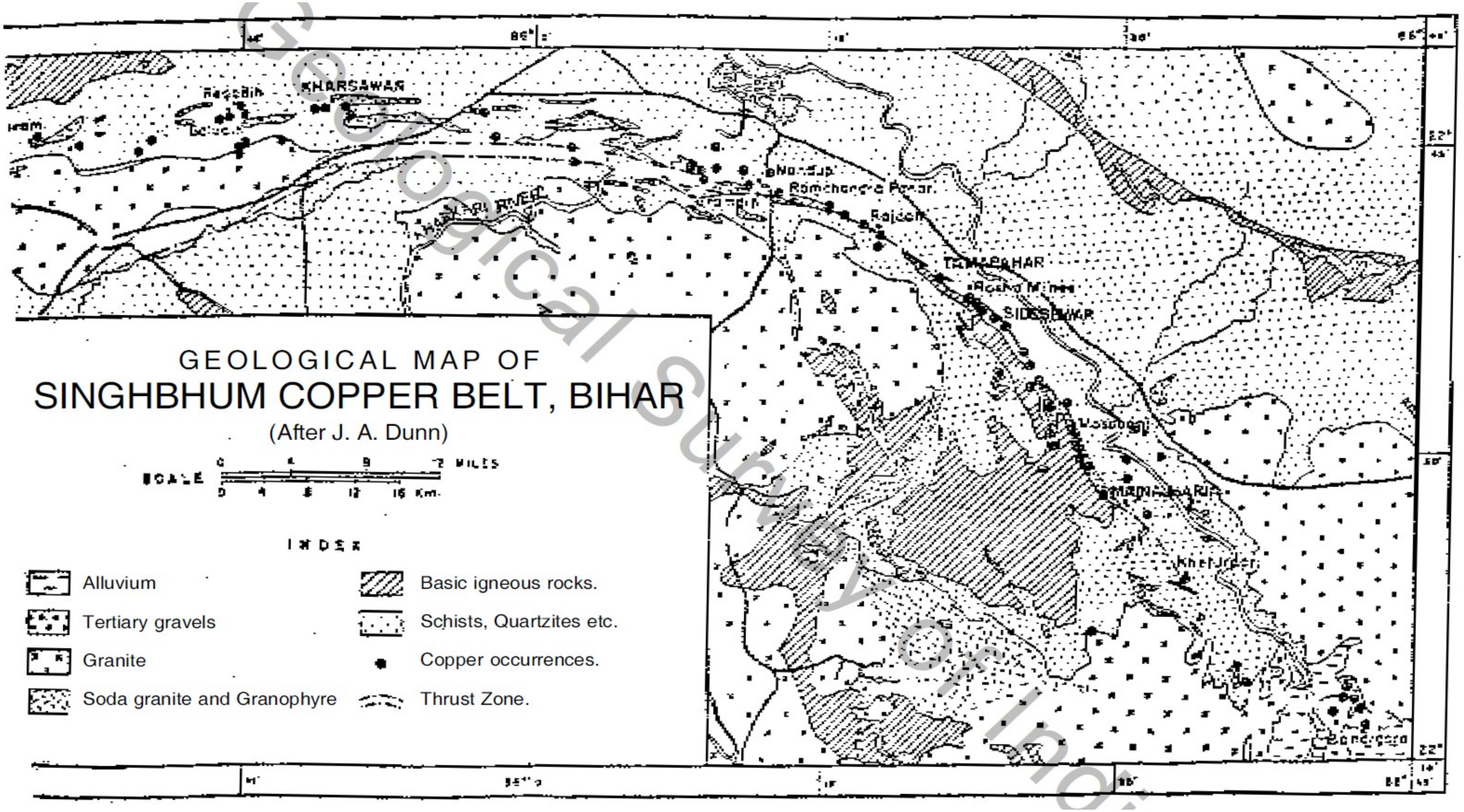
Bihar

SInghbhum Copper Belt – It is localised in a shear zone moulded along the northern and northeastern margin of singhbhum granite massif

Precambrian Archaean quartz-chlorite-biotite schist, metamorphosed basic rock and soda granite

Hesatu-Belbathan belt – The mineralised rocks occur as lenses or pockets within chotanagpur granite-gneiss

Precambrian - Tremolite-Actinolite-Schist, Calc-granulite and amphibolite



GEOLOGICAL MAP OF
SINGHBHUM COPPER BELT, BIHAR
(After J. A. Dunn)

Geological Survey of India

Chalcopyrite and pyrite are the principal sulphides in the mineralised zone. Chalcopyrite is dominant and comprises about 70 to 80% by volume of the total sulphides.

Pyrrhotite is locally developed and is more common in the deeper levels (generally at depths greater than 300 m).

The other sulphides present in the mineralised zone consist pentlandite, molybdenite, marcasite, tetradymite, tetrahedrite, cubanite and arsenopyrite, violarite, millerite etc. The principal gangue minerals are quartz, chlorite, biotite, magnetite, apatite felspar and tourmaline.

RAJASTHAN

Copper mineralisation is mostly confined to the rocks of the Delhi Supergroup in northern Rajasthan and is mostly distributed in three distinct belts: namely :

Khetri copper belt and a parallel eastern zone in Jhunjhunu and Sikar districts on the west.

Nim-Ka-Thana copper belt in Sikar district in the middle and

Alwar-Jaipur belt in Alwar and Jaipur districts on the east

KHETRI COPPER BELT, JHUNJHUNU DISTRICT

Khetri copper belt extends over a strike length of 80 m from Singhana (28°06' : 76°54') in the NNE of Raghunathgarh (27°39' : 75°21') in the SW.

It trends NNE-SSW in the northern part while to the south of Kantli river, there is a swing towards ENE-WSW. The Kantli river probably flows along a fault trending NNW-SSE with the mineralised belt to the south of the river shifted further westwards.

The Khetri copper belt is located in a semi-desert tract. It is reported that copper was mined at Khetri even during the Mauryan period. The first recorded mention of copper mining activity, during the Mughal period is in ‘Ain-e-Akbari’ (1590 AD).

The Khetri copper belt is made up of the Alwar and Ajabgarh Groups of rocks of the Delhi Supergroup (Precambrian).

The older Alwar Group predominantly comprises felspar and amphibole bearing quartzites with lenticular intercalations of phyllites, amphibolites, amphibole-magnetite rock, amphibolite etc.

The Ajabgarh Group is dominantly made up of meta-pelitic rocks, viz., phyllites with andalusite, chiastolite/staurolite; carbonaceous phyllites; biotite-schist ± garnet ± andalusite; and quartz-chlorite schist ± garnet with intercalations of banded amphibole (anthophyllite / cummingtonite) quartzite, felspathic quartzite with lenses of magnetite amphibole rock and amphibole marble ± magnetite.

Sulphide mineralisation occurs in a variety of rock types, viz., garnetiferous chlorite-quartz schist/quartzite, chlorite-biotite and amphibole bearing schist, amphibole biotite-chlorite-quartz schist, carbon phyllites, garnetiferous chlorite quartzite, felspathic quartzite, amphibole quartzite, amphibolite, amphibolemagnetite schist, andalusite bearing phyllite etc.

The bulk of the mineralisation occurs close to the contact of the Alwar quartzites with the meta-pelites of the Ajabgarh Group.

MADHYA PRADESH

Malanjkhand copper deposit:The Malanjkhand (22°02' : 80°43' - 54 B/12) copper deposit located in the Balaghat district is presently under exploitation by open cast mining by M/s. Hindustan Copper Limited.

The zone of copper mineralisation is located in the approximately 2.6 km. long arcuate Malanjkhand hill (elevation about 600 m. above m.s.l.).

The rocks of the basement complex (Malanjkhand granitoid) comprise granites and quartz reefs intruded by rnetabasics. The basement rocks are overlain by the upper Precambrian metasediments of Chilpi Ghat Series with an erosional unconformity. The granitic rocks range in composition from a biotite granite to quartz diorite and are highly kaolinised,seriticised and saussuritised in the mineralised zone. The metasediments comprise conglomerates, grits, phyllites and shales.

copper mineralisation is localised in the quartz reefs, associated with the granites.

TAMIL NADU

In Tamil Nadu, only one basemetal deposit, Viz., the multimetal copper-lead-zinc deposit at **Mamandur** is so far known.

This deposit lies in the Peninsular Archaean complex in the transition zone between charnockites on the west and migmatites on the east. The Mamandur area is made up of migmatites and charnockites with bands of garnetiferous biotite sillimanite gneiss, magnetite quartzite and a suite of ultrabasic rocks comprising pyroxenite, gabbro, norite and anorthosite. The general trend of foliation is NNE-SSW to NE-SW with dips of 60 to 65° towards SE. Galena from the mineralised zone has given an Isotope age of 2581 to 2600 M.Y.

Arumanullur (8°19'15" : 77°24'35" - 57 H/7) and adjacent areas, Kanyakumari District

In this area, sulphide mineralisation is found in meta-norite bands which occur interbanded with charnockites and garnetiferous biotite sillimanite — graphite gneisses, Incidence of pyrite - pyrrhotite - chalcopyrite have been recorded from a number of meta-norite bands occurring in the Arumanullur area and in the areas lying about 3 to 10 km to the north and north-east of Arumanullur.

KARNATAKA

Only a few small low grade deposits of basemetal are so far known from Karnataka. But a large number of occurrences of basemetal mineralisation, particularly copper mineralisation have been recorded from a variety of geological settings from different parts of the State. The deposits / occurrences can be broadly grouped into the following 4 categories

1. **Those associated with the metavolcanic - metasedimentary greenstone belts of the Dharwar Supergroup.**
2. **Those associated with sheared quartz veins and metabasic rocks traversing the granitoids of the Peninsular Gneissic Complex.**
3. **Those associated with ultramafic complexes.**
4. **Those occurring in the schist belts occurring as enclaves within thePeninsular Gneissic Complex.**

At present, two small deposits, one at Ingaldhalu located in the Chitradurga schist belt and the other at Kalyadi located in Dharwar schist enclave within the Peninsular Gneissic Complex are being worked on a scale of about 200 tonnes per day by the Chitradurga Copper Company which is a subsidiary of the Hutti Gold Mines Co., Ltd.

ANDHRAPRADESH

Several small basemetal deposits and a large number of occurrences are known from Andhra Pradesh. These deposits and occurrences are mostly hosted in rocks of the Cuddapah Supergroup and to a lesser extent in rocks of the Kurnool Group, Pakhal Supergroup, Dharwar and Sargur Supergroups and Peninsular Gneissic Complex.

The copper deposit at Mailaram in the Sargur Supergroup are being worked on a small scale respectively by M/s. Hindustan Zinc Limited and the Andhra Pradesh Mining Corporation Limited.

LEAD

This metal was probably one of the first metals to be produced by man because it is highly malleable, easy to smelt and work with. The earliest lead beads are reported from Catal Hüyük (Turkey) dated as 6400 BC.

Chemical symbol of lead ‘Pb’ is derived from Latin ‘plumbum’ for soft metal (originally ‘plumbum nigrum’ for ‘black plumbum’).

Lead metal is bright bluish-white in color when freshly cut, tarnishes to dull grey when exposed and shows a silvery lustre when melts.

It is very soft, ductile and highly malleable metal and poor in electrical conductivity. It breaks with hackly fracture and shows isometric crystal system.

It is highly resistant to corrosion, hence, is used for storage of acids. It becomes stronger by adding small amount of other metals. Earth crust shows lead concentration of 13 ppb.

Lead is poisonous, hence, is dangerous to human health. It is also the end product of radioactive decay. Lead has several isotopes but four (204Pb, 206Pb, 207Pb, 208Pb) are stable ones, and its common radiogenic isotope of 202Pb has a half-life period of about 53,000 years

Occurrence of metallic or native lead is very rare. It occurs as ore minerals mostly associated with zinc-cadmium-silver, and some copper ores in varied geological environments and different rock formations.

A total of 59 ore minerals of lead are known but the most common are galena (PbS), cerussite ($PbCO3$), anglesite ($PbSO4$) and minium ($Pb3O4$).

In Ancient Egypt galena was used as ‘kohl’ to be applied around the eyes, to reduce desert glare and repelling insects.

Within the zone of weathering or oxidation, galena alters to anglesite or cerussite.

GALENA (PbS),

Galena is the most important lead mineral and contains about 86.6% lead. Sometimes it contains silver upto 1%, hence, is known as leading silver ore.

It shows silver grey colour
with a bluish tinge,
metallic lustre,
2.5 to 2.75 hardness on Mohs scale,

7.2 to 7.6 specific gravity,

sub-conchoidal fracture and

lead-grey streak.

It occurs in isometric crystal system; often showing octahedral forms

Cerussite ($PbCO_3$),

Cerussite, also known as white lead ore or lead-spar, contains about 77.5% lead.

It crystallizes in orthorhombic system, and frequently occurs as twinned crystals, granular mass and sometimes in fibrous form.

It is colourless, white or with grey/ greenish tinge and

adamantine and resinous lustre

conchoidal fracture.

Its hardness is 3.0 to 3.5,

specific gravity of 6.5.

Initially it was used in paints and cosmetics.

Mineral: Cerussite: $PbCO_3$

Hydrocerussite: $Pb_3(CO_3)_2(OH)_2$

Comments:Platy crystals of milky white hydrocerussite covering cerussite.

Anglesite (PbSO4)

Anglesite is an oxidation product of galena
shades of various colours.

It occurs as prismatic (orthorhombic-dipyramidal) crystals and earthy masses.

hardness of 2.5 to 3.0

6.3 specific gravity

brittle to conchoidal fracture and adamantine (in crystals) and

earthy lustre.

Secondary, weathered deposits of lead ore

Anglesite: $PbSO_4$

Crystalline anglesite with minor duftite. The crystal at the top of the specimen is partially doubly terminated.

The important lead-zinc deposits of India include Rampura-Agucha (Bhilwara district), Rajpura-Dariba and Sindesar (Rajsamand district), Zawar (Udaipur), Sawar and Kayar-Ghugra (Ajmer district), Basantgarh and Deri (Sirohi district) in Rajasthan;

Amba Mata (Banaskantha district) in Gujarat;

Buniyar (Baramula district) in Jammu and Kashmir;

Rangpo and Pachekhani (East district) in Sikkim;

Rupa-Shergaon (West Kameng district) in Arunachal Pradesh;

Sargipalli (Sundargarh district) in Orissa;

Mamandur (South Arcot district) in Tamil Nadu;

Bandalamottu, Dhukonda (Guntur district) and Zangamrajupalle (Cuddapah district) in Andhra Pradesh;

Imalia (Jabalpur district) in Madhya Pradesh;

Askot (Pithoragarh district) in Uttar Pradesh; and Gorubathan (Darjeeling district) in West Bengal.

Currently lead is produced by HZL alongwith zinc at Zawar (located in Aravalli rocks), Rampura-Agucha, Rajpura-Dariba and Sindesar (located within cover sequences in BGC) mines in Rajasthan; Sargipalli mine in Orissa and Agnigundala mine in Andhra Pradesh.

Lead is the main constituent of lead-acid batteries and is widely used as a coloring agent in stained glasses for reducing the radiation transmission. Because of its high specific gravity it is used as fishing sinkers and in balancing wheels of vehicles. It is also used in polyvinyl chloride (PVC) plastic for coating the electrical metal wires, and for shielding from radiation in x-ray laboratories. In electronics its use as soldering agent is well known. Molten lead is used as a coolant in lead-cooled fast reactors. It is the traditional base metal of organ pipes, mixed with varying proportions of tin to control the tones. Sheet-lead is used for sound proofing system. Lead has many applications in building constructions e.g. sheets as architectural metals in roofing, cladding, flashings, gutters and joints, etc. It is well-known that lead was used as water proofing media (17th century) in Rajsmand Reservoir located in Udaipur district, Rajasthan.

ZINC

Chemical symbol: Zn

Atomic number: 30

Atomic mass: 65.409(4) g/mol

Melting point: 419.53°C

Boiling point: 907°C

Density: 7.14 g.cm-3

Crystal structure: hexagonal

Hardness: 2.5 Moh’s scale

Lustre: metallic

Magnetic ordering: diamagnetic

ID marks: bluish white silvery colour

Centuries before zinc was recognized as a distinct element, zinc ores were used for making brass. A prehistoric statuette containing 87.5% zinc was found in a Dacian archaeological site in Transylvania (modern Romania).

Palestinian brass from the 14th to 10th centuries BC contains 23% zinc.

The primitive alloys with less than 28 per cent zinc were prevalent in many parts of the world before India.

Brass in Taxashila has been dated from third century BC to fifth century AD.

Recently two brass bangles belonging to the Kushana period are discovered from Senuwar (U.P.), which also shows 35 percent zinc.

Zinc was rediscovered in Europe by Marggraf in 1746.

It got its name after German word ‘zinke’ for this metal.

In English and French it became ‘zinc’, in German and Dutch ‘zink’, in Spanish ‘cinc’ and in Welsh ‘sinc’ (pronounced "shink").

The Greek word for zinc is ‘pseudargyros’, literally meaning "pseudo-silver" for its silvery lustre. In Russian, it is ‘tsink’.

In India it is known as ‘Yashad’, Jasta, Jast, Naag in Hindi/ Sanskrit, Tunga in Tamil and Naagam in Malyalam.

Zinc is a bluish-white, lustrous, diamagnetic metal

Zinc makes up about 75 ppm (0.007%) of the Earth's crust. It is the 24th most abundant element in the Earth's crust. Soil contains 5 to 770 ppm of zinc with an average of 64 ppm. Seawater has only 30 ppb zinc.

After iron, aluminum and copper, zinc is the fourth-most used metal, competing with lead. A sheet of zinc looks like an aluminum sheet but it is more than twice as heavy.

The hardness of zinc at Mohs scale is 2.5. Zinc is brittle at ordinary temperatures but malleable at 100 to 150°C. Above 210°C, it becomes brittle again and can be pulverized by beating. Zinc is a fair conductor of electricity.
For a metal, zinc has relatively low melting (419.53°C) and boiling points (907°C).
Zinc is not very ductile or malleable, especially when pure.

It is relatively resistant to corrosion in air or water, and therefore, is widely used as a protective layer on iron products to protect from rusting.

Zinc is recovered from a number of different zinc ores.

The types of zinc ores include sulfide, carbonate, silicate and oxide.

Most significant of these ores are

zinc sulphide or sphalerite i.e. $(Zn,Fe)S$,

zinc carbonate or smithsonite ($ZnCO3$),

zinc silicate or willemite ($Zn2SiO4$) and

zinc oxide or zincite (ZnO).

Ores of lead, zinc, cadmium and silver often occur together.

Sphalerite $(Zn,Fe)S$ is the most important zinc ore as it contains 64.06% zinc.
It occurs mostly as veins.
It shows brown, yellow, red, green and black colour,
uneven fracture and occur as colloform (Forming from a gel or colloidal mass)17
, euhedral crystals and granular masses.
It has 3.5 to 4 hardness,
brownish white streak,
3.9 to 4.2 density and adamantine lustre.
It is fluorescent and triboluminescent.
It occurs in isometric-hextetrahedral crystal system, which is analogous to diamond.

Sphalerite is a polymorph (many shapes but same chemistry) and has two minerals i.e. wurtzite and matraite. It is sometimes difficult to identify sphalerite due to its variable colour, lustre and crystal habit.

Sphalerite: $(Zn,Fe)S$

Highly lustrous, black, complex sphalerite crystals to 15 mm in size completely covering the top of a sulfide matrix.

Yellow sphalerite crystal with small pyrite crystals on top

Sphalerite on quartz

Sphalerite on quartz

Sphalerite on quartz

Sphalerite on calcite

The smithsonite ($ZnCO_3$), commonly shows various shades of green and purple;

has a silky to pearly lustre; and occurs in trigonal crystal system and botryoidal form.

It shows white streak, hardness of 4 to 4.5 and specific gravity of 4.4.

Fraipontite: $(Zn,Al)_3(Si,Al)_2O_5(OH)_4$
Zinalsite: $Zn_2AlSi_2O_5(OH)_4\cdot 2(H_2O)$ (?)
Smithsonite: $ZnCO_3$

Pearly white, sub-mm fraipontite (zinalsite) crystals associated with green smithsonite.

Creedite: $Ca_3Al_2(SO_4)(F,OH)_{10}\cdot 2(H_2O)$
Smithsonite: $ZnCO_3$

Purple transparent crystals of creedite to 6 mm on matrix of creamy botryoidal crystalline smithsonite.

The willemite(Zn_2SiO_4) is somewhat rare zinc mineral. It has vitreous to resinous lustre, hardness of 5.5; specific gravity from 3.9 to 4.2, trigonal crystal system, conchoidal to uneven fracture and white streak. It fluoresces a bright green colour under ultra-violet light. Some willemite specimens even show phosphorescence. Phosphorescence is the ability of a mineral to glow after the initial light is removed.

Sky blue botryoidal willemite with dark to white dolomite.

Pinkish gray crystalline glaucochroite intermixed with pale green willemite, with dark red zincite and white calcite.

The **zincite ($Zn2SiO4$)** is also rare zinc mineral, which is orange-yellow to deep brown or red in colour. It shows orange-yellow streak, conchoidal fracture, hardness of 4 and specific gravity between 5.4 and 5.7. It occurs in hexagonal crystal system forming small crystals and masses

Zincite: $(Zn,Mn)O$

Orange Zincite hexagonal pyramid.

Zinc ores occur in a variety of geological environment Principal lead-zinc deposit types include carbonate-hosted ores, sandstone-hosted ores, shale-hosted deposits and volcanogenic deposits.

Zinc mines are throughout the world with the largest producers being Australia, Canada, China, Peru and United States. Most zinc mines are underground (80%) but some are of the open pit type (8%). China produced 2,600,000 tonnes i.e. one-fourth of the global zinc output in 2006 while India produced 420,000 tonnes.

Important zinc-lead deposits, mostly localized within Precambrian peninsular shield, include Zangamrajupalle and Gollapalle in A.P.; Amjhore within Vindhyan rocks in Bihar; Amba Mata in Delhi Supergroup of rocks in Gujarat; Kolari within Sakoli Group of rocks in Maharashtra; Agucha within Banded Gneissic Complex; Deri and Kayar-Ghugra within Delhi Supergroup; Rajpura-Dariba, Devpura, Samodi, Sindesar and Tiranga within Pur-Banera belt of Pre-Aravalli; and Paduna and Zawar within Aravalli Supergroup of rocks in Rajasthan; Mamandur within Peninsular Archaean Complex of rocks in Tamil Nadu; and Gorubathan within Extra-peninsular Daling Formation (Pre-Cambrian - Cambrian) in West Bengal.

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Agucha within Banded Gneissic Complex;

Deri and Kayar-Ghugra within Delhi Supergroup;

Rajpura-Dariba, Devpura, Samodi, Sindesar and Tiranga within Pur-Banera belt of Pre-Aravalli; and Paduna and Zawar within Aravalli Supergroup of rocks in Rajasthan;

Mamandur within Peninsular Archaean Complex of rocks in Tamil Nadu; and

Gorubathan within Extra-peninsular Daling Formation (Pre-Cambrian - Cambrian) in West Bengal.

Zinc production in India initially was done by government through a public sector company i.e. Hindustan Zinc Limited. It was the biggest company in India, which took care of mining to extraction of zinc.

In April 2002, HZL was privatized. Vedanta Group (still named HZL) is now conducting mining and production zinc and associated metals in the country. Reserves and resources of 232.3 Mt of ore containing 27.5 Mt of zinc-lead metal are present as on 31.3.08.

HZL's operations include three lead-zinc mines (Agucha in Bhilwara district, Zawar in Udaipur district and Rajpura-Dariba in Rajsamand district in Rajasthan), three zinc smelters (Debari and Chanderiya in Rajasthan; Vizag in A.P.).

HZL's zinc production increased from 283,698 tonnes in 2006 to 426,323 tonnes in 2008. The expansions at the Sindesar Khurd and Kayar mines will be completed in phases by early 2012. A zinc smelter of Binani is located at Alwaye in Kerala.

Molybdenum

Molybdenum is a refractory metal used principally as an alloying agent in steels, cast irons and super alloys to enhance hardness, strength, toughness and wear and corrosionresistance.

Primarily added in the form of molybdic oxide or ferromolybdenum, it is frequently used in combination with chromium, columbium, manganese, nickel, tungsten or other alloy metals to achieve desired metallurgical properties.

The versatility of molybdenum has ensured it a significant role in contemporary technology and industry, which increasingly require materials that are serviceable under higher stresses, greater temperature ranges and more corrosive environments.

Moreover, molybdenum finds significant usage as a refractory metal in numerous chemical applications including catalysts, lubricants and pigments.

The variety of molybdenum materials, few of which afford acceptable substitutions has resulted in a demand that is expected to grow at a greater rate than most other ferrous metals.

From the period of the Greek and Roman civilizations to the late 18th century, terms such as ‘molybdaena’ were applied to minerals that were soft and ‘lead like’ in character, probably including minerals now known as galena, graphite and molybdenite.

This confusion was resolved in 1778 when the Swedish chemist, Karl Scheele, demonstrated that molybdenite, the principal molybdenum mineral was a discrete mineral sulphide.

World War I generated the first appreciation of utilisation of molybdenum, when it was substituted for tungsten in high speed steels and used as an alloying element in certain steels for military armament.

The Climax deposit in Colorado and the Questa deposit in New Mexico were initially exploited from 1917 to 1919. Development of the Climax deposit being the world’s largest, proved the viability of high tonnage extraction of relatively low grade ore and established United States as the leading producer of molybdenum.

Molybdenum is a silver-white metallic element with an atomic number of 42, atomic weight of 95.95 and a density of 10.2 grams per cubic centimetre.
Molybdenum is a strong carbide forming element and much of its alloying effect in steel is imparted through the formation of carbides. It has a melting point of about 2,610°C.

significant physical properties of molybdenum metal are good thermal conductivity (about one half that of copper), the lowest coefficient of thermal expansion of the pure metals, high strength at elevated temperatures and resistance to corrosion in a variety of mediums. Molybdenum metal is stable in air or water at moderate temperatures but above 500°C, it oxidises readily.

Molybdenum does not occur in nature in its free or native state, but is found only in chemical combination with other elements. Small deposits of molybdenum bearing minerals occur throughout the world, but the only molybdenum mineral of commercial importance is molybdenite. Wulfenite, powellite and ferrimolybdite are common but have provided very little molybdenum.

Chemical Formula: MoS2

Help on Composition: Composition:

Molybdenum	59.94 %	Mo
Sulfur	40.06 %	S

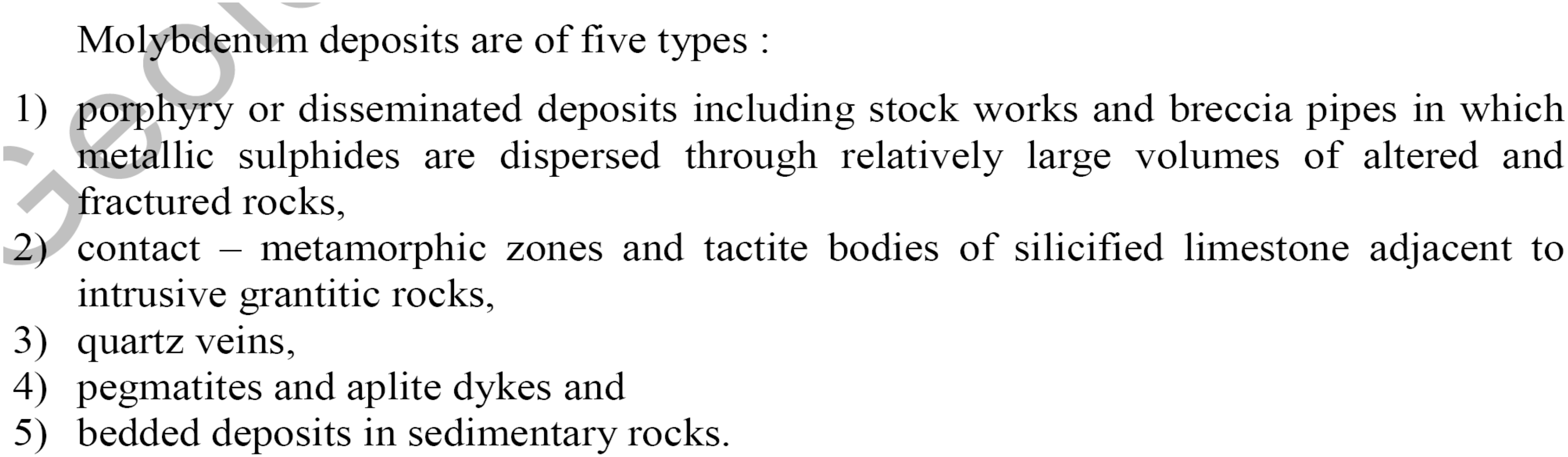
Cleavage:{0001} Perfect
Color: Black, Lead gray, Gray.
Density: 5.5
Diaphaneity: Opaque
Fracture:Sectile - Curved shavings or scrapings produced by a knife blade, (e.g. graphite).
Habit:Disseminated - Occurs in small, distinct particles dispersed in matrix. Foliated. Massive
Hardness: 1 - Talc
Luminescence: Non-fluorescent.
Luster: Metallic
Magnetism: Nonmagnetic
Streak: greenish gray

Molybdenite: MoS2

Sharp metallic molybdenite crystal on matrix.

Molybdenite (MoS_2) is a lead-grey metallic mineral that characteristically occurs in thin, tabular, commonly hexagonal plates and also disseminated as fine specks. It has a specific gravity of 4.6 to 4.7, a hardness of 1 to 1.5, a greasy feel and it soils the fingers.

Superficially, it resembles graphite, for which it is commonly mistaken. However, molybdenite differs from graphite by bluish tinge.



Molybdenum deposits are of five types :

1) porphyry or disseminated deposits including stock works and breccia pipes in which metallic sulphides are dispersed through relatively large volumes of altered and fractured rocks,
2) contact – metamorphic zones and tactite bodies of silicified limestone adjacent to intrusive grantitic rocks,
3) quartz veins,
4) pegmatites and aplite dykes and
5) bedded deposits in sedimentary rocks.

Molybdenite concentrate is converted to technical grade molybdic oxide.

Molybdic oxide is the major form of molybdenum used by industry and the base material for production of ferromolybdenum, chemicals and molybdenum metal powder.

WORLD RESOURCES

Geological

The molybdenum reserves in the U.S.A. account for 49% of the world's total reserve. Nearly 90% of the American resources occur in great porphyry or disseminated deposits in Alaska, Colorado, Idaho, Nevada, Novo Mexico and Utah. In Canada, the primary molybdenum reserves occur in the Endako deposit (30%), British Columbia and other smaller resources occur in porphyry sometimes associated with copper in Quebec and New Brunswick. In Chile and Peru, molybdenum reserves occur mainly in great porphyry copper. In Chile, Chuquicamata and EI Teniente are among the largest in the world and represent 85% of the Chilean resources. In Mexico, La Caridad is considered a big producer. Peru has great reserves. Other porphyry copper deposits, which might contain exploitable molybdenum reserves have also been found in Central and South America, many of these are being explored and evaluated and could increase future reserves. Quite large reserves of molybdenum are found in China and the former Soviet Union may be quite large, but supply and demand data are lacking. In the Southwest Pacific islands, New Guinea and Bougainville, there are some copper exploration projects in progress but results are pending. In Brazil molybdenum reserves occur in association with Copper and Gold in Para State, Carajas, in the Salobo Mine. Other non-evaluated occurrences are found in different states.

Table – 3
World Reserves and Production of Molybdenum

Specifications	Reserves (‘000 tons)		Production (tons)		
Countries	**2001 (p)**	**%**	**2000 ®**	**2001 (p)**	**%**
Brazil	-	-	-	-	-
Armenia	30	0.3	2700	2700	2.0
United States	5400	49.0	41100	38300	28.8
Canada	910	8.3	6830	6800	5.1
Chile	2500	22.7	29100	35000	26.3
China	1000	9.1	28900	28900	21.7
Iran	140	1.3	1600	1600	1.2
Mexico	230	2.1	6890	6900	5.2
Mongolia	50	0.4	1340	1400	1.1
Peru	230	2.1	7190	7200	5.4
Russia	360	3.3	2400	2400	1.8
Other	150	1.4	950	1800	1.4
TOTAL	11000	100.0	129,000	133,000	100.0

ical Survey of In

INDIAN OCCURENCE

There is no known occurrence of primary molybdenite, which is presently being mined in India. The annual requirement of molybdenum is met by imports.

There is a meagre contribution to India's requirement of molybdenum from Uranium Corporation of India (UCIL) which is producing molybdenite concentrate as a by-product of its uranium mill at Jaduguda, Bihar.

However, incidence of primary molybdenite is known from different parts of India

Geological Setting and Resources

The geological setting and mode of occurrence of the molybdenum mineralisations vary widely.

It occurs in granite plutons or their associated aplites, pegmatites or quartz veins as is known in the Ambalavayal granite in Kerala of Southern Granulite Terrain, younger granitoids of Bundelkhand and Baster cratons in parts of Madhya Pradesh and Chattisgarh respectively and in the Myliam granite in the Meghalaya craton.

Molybdenite is also known from the metasediments of the Delhi Super Group of Rajasthan and the Sausar Group of Maharashtra.

The molybdenite prospects of Dharmapuri district of Tamil Nadu are referable to the late phase hydrothermal activity related to the Alkaline Carbonatite intrusives in the rift valley setting.

The incidence is also known in the amphibolites of Kolar Schist belt in the Kudithinapalli area and in the adjoining gneiss in Andhra Pradesh.

In Rajasthan, molybdenite occurs as an associated mineral with copper in the Khetri Copper Belt while in Jharkhand it occurs in small quantities along with copper and uranium in the Singhbhum shear zone. In the Kolar Schist belt, it is associated with gold and galena. However, it may be generalised that molybdenite always occurs in association with other sulphides.

The controls of mineralisation also show considerable variation.

Shear zone forms the major control for the prospects in northern Tamil Nadu, Kudithinapalli in Andhra Pradesh and Singhbhum shear zone in Jharkhand.

The occurrence in Rajasthan is controlled by fold hinges.

The Contact of the meta sedimentary of the Sausar Group and the intrusive constitute the control in Maharashtra.

The occurrence in Meghalaya and Kerala are controlled by fracture systems in and around the granite plutons.

Molybdenite occurrences of Southern Granulite Terrain viz., Harur-Uttangarai,Alangayam-Rasimalai, Danishepet, Toppur, Pakkanadu, Kurichi (all these locations fall within Dharmapuri Suture Rift Zone (DSRZ) of Northern Tamil Nadu),

Ambalavayal (Northern Kerala, along Bhavali – Moyar Shear Belt), Karadikuttam - Palayam (Madurai Terrain of South Central Tamil Nadu) and Putteti (Nagarkoil Terrain of Southern Tamil Nadu)

The fracture filing/stock work type of molybdenite mineralisation occurs in alkali granite (595 ± 20 Ma) of Ambalavayal area, in the late pink syenite body east of Elagiri Complex (720 Ma) and in Pakkanadu Syenite Complex (610 Ma).

In Putteti area molybdenite is seen disseminated within the coarse grained syenite dykes which cut through the layered syenite intrusives (580 Ma).

The quartz vein type molybdenite mineralisation is exposed in different parts within the DSRZ. These quartz (± barite ± carbonates) veins of DSRZ are considered the end phase of the alkali – carbonatite magmatism (620 to 800 Ma) of northern Tamil Nadu.

In Karadikuttam area molybdenite mineralisation is seen in association with the pegmatite and aplite veins. In Palayam, molybdenite is observed at the contact zone between crystalline limestone and pegmatite.

As per the UNFC (as on 1.4.2000), the total resources of molybdenum ore in the country are estimated at about 16.29 million tones containing about 10,500 tonnes MoS2.

DIAMOND

- **The ancient Indians were the first in the world to take notice of the mineral diamond for its beauty and hardness. Diamond was discovered by the Indians in the eighth century B.C.**

- **They used to collect diamonds from its secondary sources i.e., the quaternary gravel beds and gravelbars in the sediments.**

- **Despite this ancient tradition, the primary sources of diamonds (kimberlite, lamproite, and other kimberlite clan rocks) have been found in India only after its Independence (except the Majhgawan pipe, Panna Madhya Pradesh).**

- **The diamondiferous Majhgawan pipe has operated as India's only significant primary diamond mine with a grade of about 10 carats per hundred tonnes.**

- Diamond occurrences in India are quite widespread. Information on the ancient diamond mines and geology of the diamond bearing strata is available from the writings of the medieval period European travellers traders and Portuguese and British officials and geologists of the Geological Survey of India (GSI).

- Systematic geological details are obtained from the investigations carried out for diamonds since, 1950's, mostly by the GSI, which were at peak in 1980s with implementation of National Diamond Project, aimed at assessing the diamond potentials of different known host rocks.

- Subsequent works were oriented towards locating primary host rock for diamond and many kimberlite bodies in the already known areas and new kimberlite/lamproite fields in virgin areas were discovered

- The known areas of occurrences of diamond source rocks are broadly grouped into three diamond provinces, namely the South Indian Diamond Province (SIDP), the Central Indian Diamond Province (CIDP) and the East Indian Diamond Province (EIDP).

- Each of these Provinces extends approximately over an area of 100,000 sq. km and includes both primary (Kimberlites/Lamproites) and secondary source rocks (conglomerates and gravels) for diamond.

- The SIDP is confined to the Dharwar Craton in the states of Andhra Pradesh, Karnataka and Maharastra, the CIDP to the Aravalli Craton in the states of Madhya Pradesh, Rajasthan and Uttar Pradesh and the EIDP to the Bastar and Singhbhum Cratons in the states of Maharastra,Chhattishgarh, Orissa, Jharkhand and Madhya Pradesh.

Considering the Cratons and presence of diamonds and the source rocks, areas have been prognosticated for kimberlite search in India.They are:

(1) South Indian Diamond Province (SIDP) including East Dharwar Craton and adjoining Dharwar Mobile Belt; (2) West Dharwar Province; (3) East Bastar Craton including parts of Eastern Ghat Mobile Belt (EGMB); (4) West Bastar Craton; (5) Southern part of Bundelkhand – Aravalli Craton ; (6) North of Central Indian Suture (CIS); (7) Southern part of Singhbhum Craton including Singhbhum Mobile Belt; (8) Raigarh Mobile Belt; (9) Structural Corridor of Son – Narmada rift zone; (10) Structural Corridor of Tapti Lineament Zone; (11) Mahanadi Gondwana Graben and (12) Godavari Gondwana Graben.

The SIDP consists of both primary and secondary source rocks of diamond. The kimberlites localised within the Eastern block of the Dharwar Craton are grouped into three fields, namely Wajrakarur Kimberlite field, (WKF), Narayanpet kimberlite Field (NKF) and Raichur Kimberlite Field (RKF).

The major lamproite dykes occurring along the eastern margin of the Craton i.e. within the Nallamalai Fold Belt (NFB) and close to the north eastern margin of the Cuddapah basin are included in the Chelima Lamproite Field (CLF) and Jaggayyapeta Lamproite Field (JLF) respectively.

The CIDP also consists of primary and secondary source rocks. The NE-SW trending Panna Diamond belt with established ancient mining activity is located within this province.

This is the only belt where active mining for diamond is presently carried out in the country. The National Mineral Development Corporation Ltd is exploiting Majhgawan kimberlite/lamproite, the only diamond producing mine.A little amount of diamond is being recovered from placer occurrences.

Diamond has been the most priced among the gems since more than 2000years.The price of diamond depends upon its weight, quality, shape and flawlessness. Diamond has a high refractive index and strong dispersion which gives it that exciting brilliance when cut as facetted stone.

Gem diamonds are transparent and colourless or show faint shades of different colours. The transparent water clear diamonds are known as " of first water" or "blue white". When yellowish tinge is present, they are termed as off-colour stones. Diamonds with green, blue or red shades are rare but are most valuable gems.

RESERVES OF DIAMOND (BY STATES/GRADES) (IN CARATS)

State/Grade	Recoverable reserves (As on 1.4.1995)			
	Proved	Probable	Possible	Total
India(Grade: Unclassified)	851156	-	130359	981515
By States				
Andhra Pradesh	5465	-	-	5465
MadhyaPradesh	845691	-	130359	976050

PRODUCTION & STOCKS

Production of diamond at 57,406 carats in 2000-2001 registered an increase of 40% over the previous year. There are two reporting mines both in public sector located in Panna district of Madhya Pradesh.

Of these, one mine, owned by National Mineral Development Corporation Ltd (NMDC) contributed as much as 99% to the total output of diamond and the remaining 1% was by the Department of Geology & Mining, Govt of Madhya Pradesh.

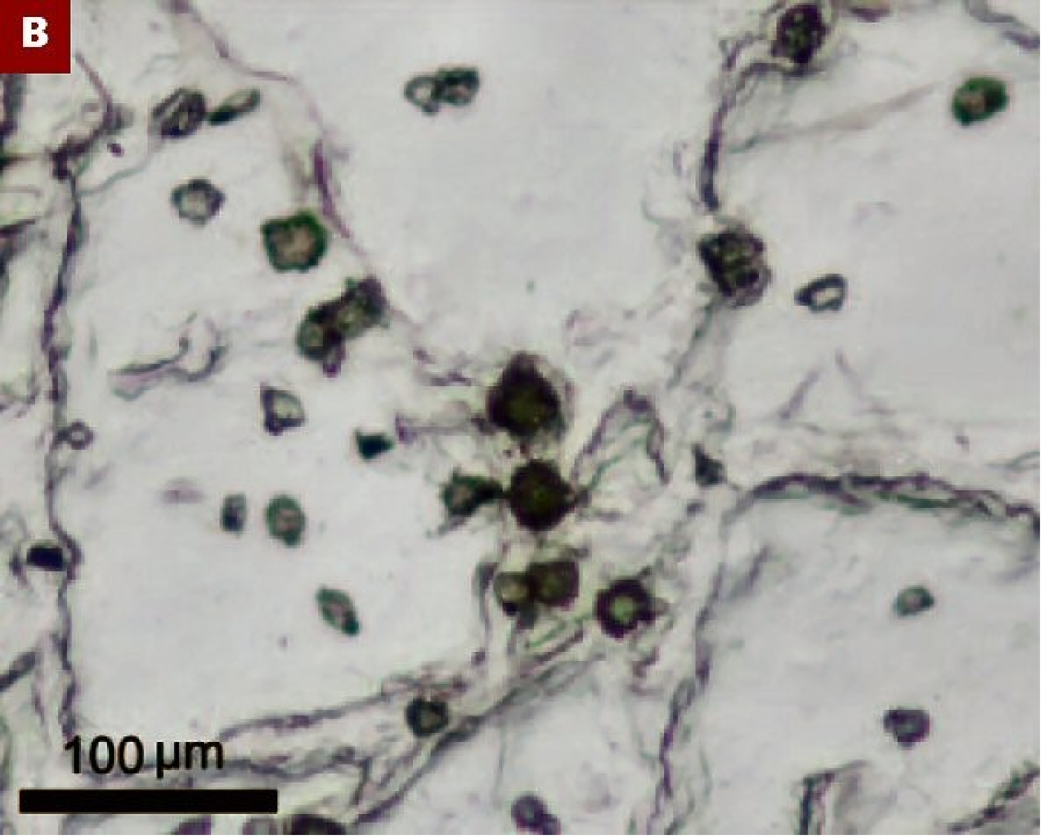
Name and address of producer.	Location of Mine	
	State	District
National Mineral development Corporation. Ltd. 10-3-311/ A, Castle Hills, Masab Tank, Hyderabad- 500028, A.P.	Madhya Pradesh	Panna
Director of Geology & Mining, Government of Madhya Pradesh, Panna, Dist Panna, Madhya Pradesh	Madhya Pradesh	Panna

India

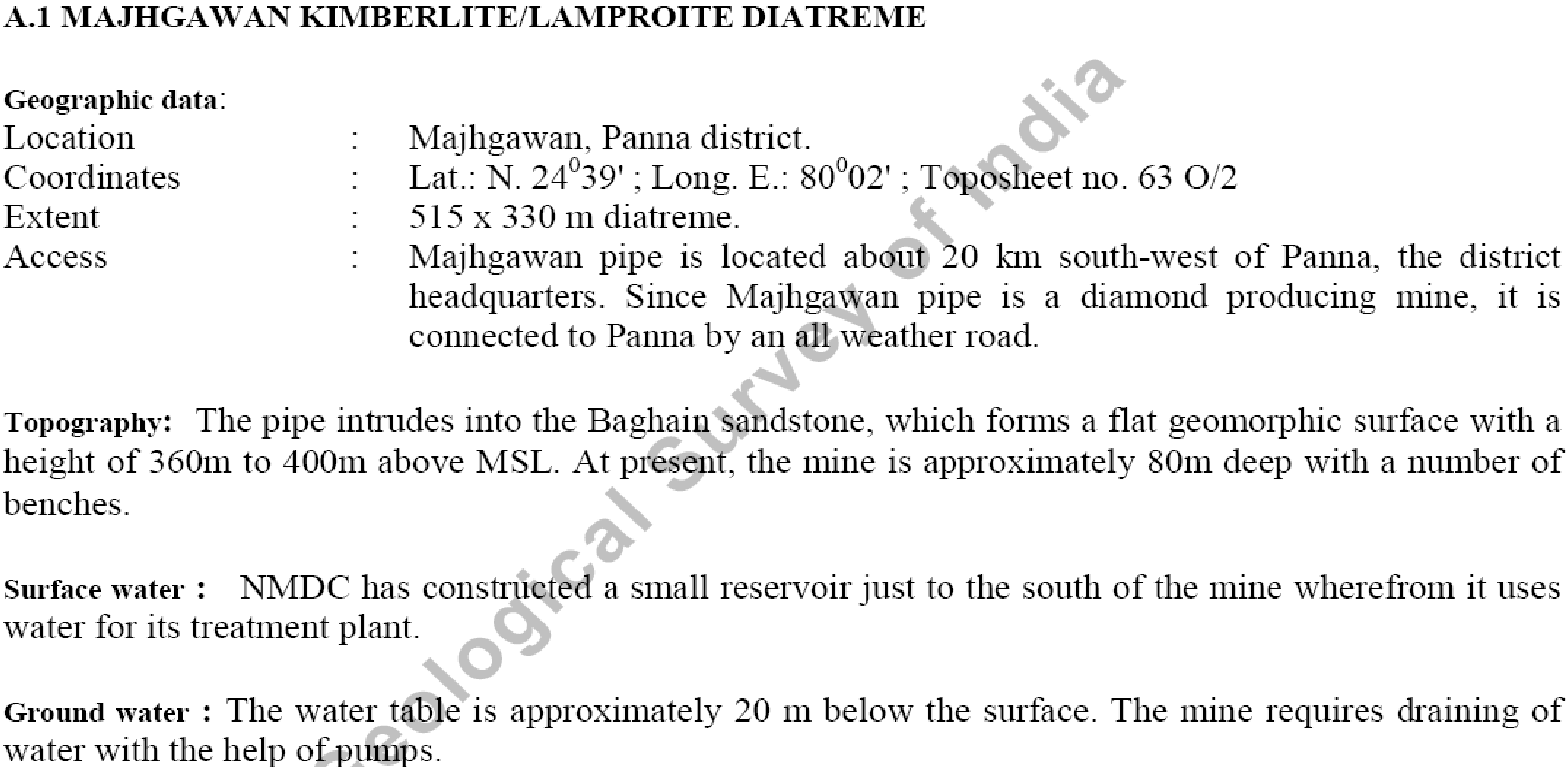
CHEMISTRY C Carbon
CRYSTALLOGRAPHY Isometric (Cubic)
CRYSTAL GROWTH AND HABITS Most crystals of Diamond are modified octahedrons but they are also found as dodecahedral, tetrahedral or cubic crystals. Diamond crystals are commonly flattened or elongated and are also found as crude spheres with a radial structure.
COLOR AND OTHER OPTICAL PROPERTIES Diamonds are colorless, pale yellow to deep yellow, brown or bluish. Other colors of diamond are also known. Diamond is transparent to translucent and even opaque, depending on the amount of impurities (commonly graphite).
HARDNESS 10
SPECIFIC GRAVITY 3.5
LUSTER Adamantine to greasy
STREAK White
BREAKABILITY Diamond has a very good octahedral cleavage (4 directions) and also has conchoidal fracture and is brittle.
OCCURRENCE Diamonds are formed in high temperature, high pressure environments as in igneous kimberlite pipes or dikes. Diamonds are also found as placer deposits.
ASSOCIATED MINERALS Olivine, Phlogopite, Pyrope, Diopside, Ilmenite

Elongated, flattened crystal of Diamond in a matrix of Kimberlite, from South Africa.

Origin: South Africa
Sample size: each approx. 1 cm on edge (17.4 carats total weight)



Mineral:	Diamond: C
Comments:	Photomicrographs (PPL) of numerous microdiamonds in Kumdy-Kol caboniferous dolomite marble (Elements v1, no 2).
Location:	Kokchetav Massif, Kumdy-Kol ultra high pressure facies area, northern Kazakhstan.



A.1 MAJHGAWAN KIMBERLITE/LAMPROITE DIATREME

Geographic data:

Location	Majhgawan, Panna district.
Coordinates	Lat.: N. $24^{0}39'$; Long. E.: $80^{0}02'$; Toposheet no. 63 O/2
Extent	515 x 330 m diatreme.
Access	Majhgawan pipe is located about 20 km south-west of Panna, the district headquarters. Since Majhgawan pipe is a diamond producing mine, it is connected to Panna by an all weather road.

Topography: The pipe intrudes into the Baghain sandstone, which forms a flat geomorphic surface with a height of 360m to 400m above MSL. At present, the mine is approximately 80m deep with a number of benches.

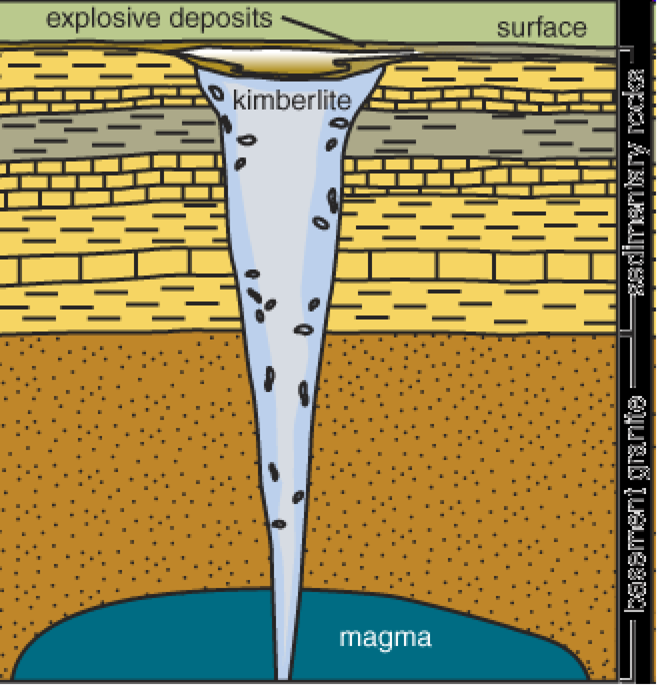
Surface water : NMDC has constructed a small reservoir just to the south of the mine wherefrom it uses water for its treatment plant.

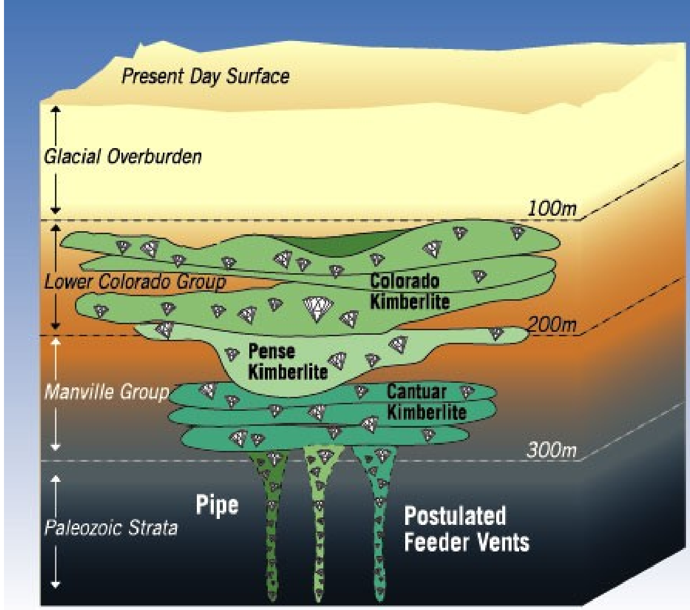
Ground water : The water table is approximately 20 m below the surface. The mine requires draining of water with the help of pumps.

Geological Survey of India

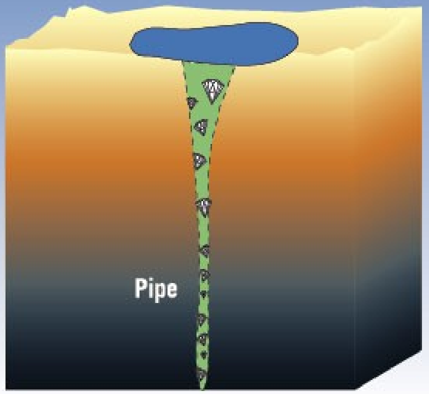
There are five varieties of kimberlite:

1. Basaltic kimberlite with phlogopite.
2. Basaltic kimberlite without phlogopite.
3. Kimberlite breccia with phlogopite.
4. Kimberlite breccia without phlogopite and
5. Kimberlite breccia with abundant phlogopite





Fort à la Corne, Saskatchewan



South Africa and Northwest Territories

KIMBERLITE PIPE IN AUSTRALIA


Photographie Simon Sheppard